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RADIO RECEIVING SETS WITH LINEAR ACTION TUNING CONDENSERS

621.396.662.1 : 621.396.662.6

For the sake of commodity in direct tuning by push-buttons a new type of tuning condenser has been developed, in which the variation of the capacity is obtained, not by the rotation of two sets of plates, but by a linear displacement of one set with respect to the other. Particulars of these linear action tuning condensers are given in this article, as well as a description of a system of push-button tuning in which this type of condenser is used. Upon repeated pressing of a button the required tuning is reproduced accurately to within 0.5 kc/sec on an average, and in the most unfavourable wave-length range to within 1 kc/sec. The means by which this great accuracy is obtained are discussed in conclusion.

In addition to the ordinary hand tuning, radio sets are now being provided to an increasing extent with push-button tuning, whereby certain stations need not be found but simply switched on. An article appeared a year ago in this periodical [1]) describing the different systems of push-button tuning. It was shown that for various reasons a mechanical system is preferable, *i.e.* a system in which the electrical part remains entirely unaltered, and in which the push-buttons only determine the position of the tuning condenser by means of a stop. There are two possibilities: the tuning condenser may be brought directly into its final position by the movement of the push-button, or the push-button may switch on a motor which moves the tuning condenser. The second method permits a somewhat greater accuracy but requires more elaborate auxiliary apparatus than the first. In the following we shall concern ourselves only with the first method in which the push-buttons bring the tuning condenser into motion directly.

When ordinary rotating condensers are used there is a certain amount of difficulty due to the fact that the condenser plates must describe a large angle (generally 180°) in order to increase the capacity from the minimum to the maximum value. Therefore the push-button must either cover considerable distance in its movement, or, when the distance is shortened by means of a system of levers, its movement requires considerable force. The necessary angle of rotation for maximum capacity could be made smaller by decreasing the distance between the condenser plates. The required maximum capacity would then be obtained with a smaller surface so that the plates would only need to overlap over a smaller angle. A limit is, however, set by the bending which may occur in the condenser plates and which might lead to short circuit with too small a separation between the plates.

A new type of tuning condenser has been developed by Philips which is in principle much less subject to the above-mentioned restriction. The "plates" of this new condenser are not flat but curved, and they therefore have a much greater resistance to bending in a certain direction. Variation of the effective surface of the condenser is brought about in this case, not by rotation, but by linear displacement of the sets of plates relative to each other. This linear action condenser and its application in a push-button tuning system will be described in this article.

The linear action tuning condensers

The two sets of plates of the linear action condenser are shown in *fig. 1*. Each set consists of a brass strip 0.1 mm thick wound in the form of a spiral of Archimedes and soldered to a base plate. If one of two such identical spirals is turned through 180°, the windings of the one spiral fall exactly midway between those of the other (*fig. 2*). This follows directly from the fact that in the case of the spiral of Archimedes the radius vector is proportional to the angle. Two bodies with such

[1]) A. Horowitz and J. A. van Lammeren, Radio receivers with push-button tuning, Philips techn. Rev. 3, 253, 1938.

a spiral cross section can therefore be fitted together without making contact. The distance between the two spirals is equal to one half the

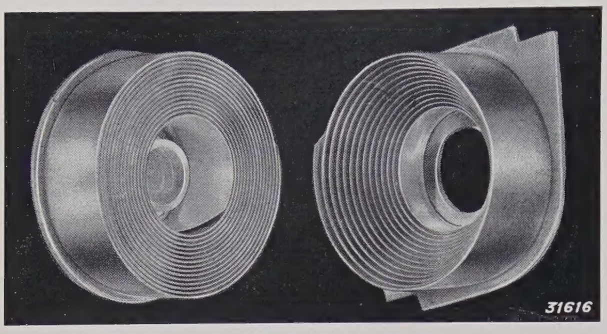

Fig. 1. The two sets of plates fitting into one another of the linear action tuning condenser. Each set consists of a strip wound in the form of a spiral of Archimedes.

distance between the windings of one spiral less the thickness of the material, and in the case in question it is 0.2 mm. This very small distance is attainable thanks to the above-mentioned fact that the curved "plates" are extremely stiff in a radial direction, and the bending at the free edge (that not soldered to the base plate) remains small enough to be neglected even upon powerful shocks. Moreover due to the light and compact construction no great mass forces occur. The lower limit for the permissible distance between the plates in this type of construction is rather prescribed by the necessary play in the bearings and the inevitable variations in the thickness of the brass strip. For a plate distance of 0.2 mm these variations must not surpass 0.003 mm.

The sets of plates have a maximum diameter of about 35 mm. Because of the smallness of the separation between the plates the maximum capacity of about 500 $\mu\mu$F necessary for a frequency range of 500 to 1 700 kc/sec is already obtained when the two sets of plates overlap by about 10 mm. A relative displacement of the two parts of the condenser of only 10 mm is therefore sufficient for the command of the wave-length range mentioned.

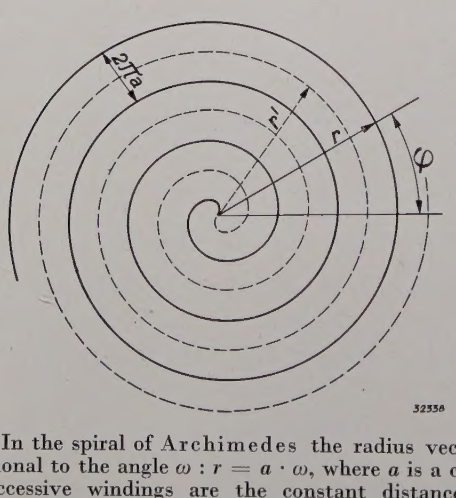

Fig. 2. In the spiral of Archimedes the radius vector r is proportional to the angle ω : $r = a \cdot \omega$, where a is a constant The successive windings are the constant distance $a \cdot 2\pi$ apart. A second identical spiral which is rotated one half a turn has the equation $r' = a\ (\omega + \pi)$. The windings of this spiral therefore lie exactly midway between the windings of the first.

The smallness of the maximum displacement makes it possible to set the condenser by means of a push-button with a slight depression and requiring only a small force. It also, however, makes it necessary that the relative position of the sets of plates be very accurately determined for a definite frequency. If the requirement is made that the tuning shall be reproducible with a deviation of 0.5 kc/sec — it has been found that this accuracy is quite sufficiently in practical cases —, then, with a linear relation between frequency and displacement, the

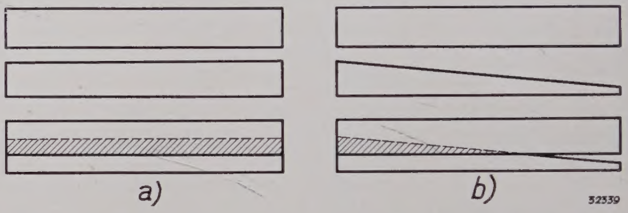

Fig. 3. a) If both of the strips which are wound to form the spirals are cut off straight, the capacity of the condenser is proportional to the length over which the two parts overlap.
b) If one of the two strips is cut off obliquely the capacity varies with the square of the relative displacement as long as the resulting conical part (see fig. 1) of the spiral body is not yet completely overlapped by the other spiral.

position of the moving part of the condenser must be accurately defined within

$$10 \cdot 0.5/(1700—500) \approx 0.004 \text{ mm}.$$

The requirement becomes higher when the relation between frequency and displacement is not linear, so that in a certain part of the scale the transmitters equidistant in frequency fall closer to one another. If the two strips of brass making up the sets of plates are cut off straight (*fig. 3a*) such a crowding of stations is actually obtained in the region of shorter wavelengths. This is illustrated by means of *fig. 4a*. If, however, one of the condenser spirals is given a conical cavity (visible in fig. 1 at the right), by cutting one edge of the strip obliquely (fig. 3*b*), the relation between frequency and displacement can be made fairly approximately linear, and the stations are distributed quite uniformly over the entire scale (fig. 4*b*). In this way, with an accuracy of 0.005 mm in the position of the condenser, the deviation in frequency is less than 0.5 kc/sec in the greatest part of the whole frequency range and less than 1 kc/sec

in the most unfavourable frequency range. At the end of this article we shall discuss the measures which made it possible to obtain the required accuracy in the setting of the condenser.

For the simultaneous tuning of different circuits a number of similar condensers are mounted on the same shaft, just as in the case of the rotating condenser. In *fig.* 5 such a system of three linear action condensers is shown. The stationary parts of the three condensers, fastened into the frame with insulators, have a central opening through which passes the steel shaft which carries the three moving sets of plates. In a practical case it is important that the maximum capacity (capacity when the sets of plates are completely overlapping) of each condenser should have exactly the prescribed value. This adjustment can be carried out very simply during assembly by slightly rotating the two spirals with respect to each other. The windings of the one spiral then no longer fall exactly midway between the windings of the other. If for example in fig. 2 the dotted spiral is turned in a clockwise direction through a small angle, then starting at the centre of that spiral it will be seen that it is now closer to the other spiral on the right and farther away from it on the left. A change in the capacity is hereby obtained like that obtained in the simple case of a plate condenser (see *fig. 6a*) where a middle plate is displaced with respect to two connected outer plates. This case is indicated in fig. 6*b*. It is clear that the capacity can be accurately regulated by means of slight displacements (rotation of the spiral) about the middle position.

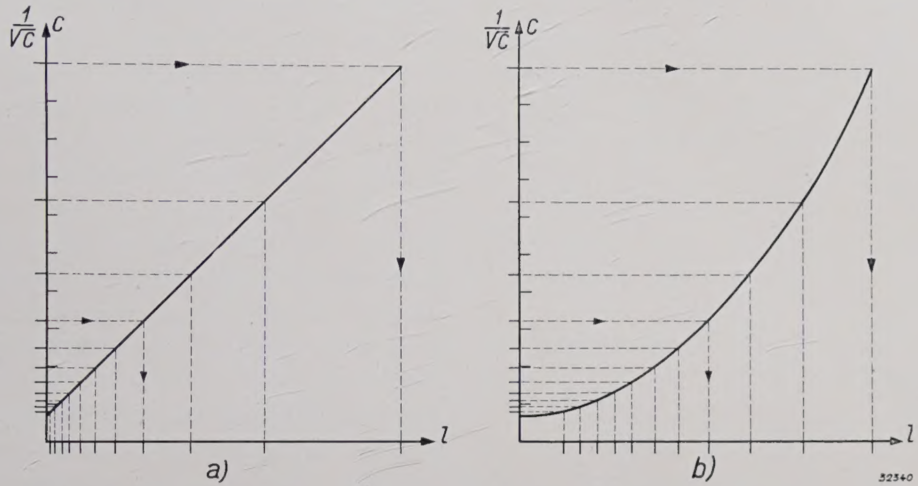

Fig. 4. *a*) The capacity C is plotted as a function of the displacement l for the case of fig. 3*a*. On the C axis a number of aequidistant values of $1/\sqrt{C}$ (*i.e.* a series of transmitters with a constant difference in frequency) is indicated. If this distribution is projected on the l axis it will be seen that the transmitters become crowded together at one end of the scale.
b) Same as *a*) drawn for the case of fig. 3*b*. All the transmitters are now distributed uniformly over the scale.

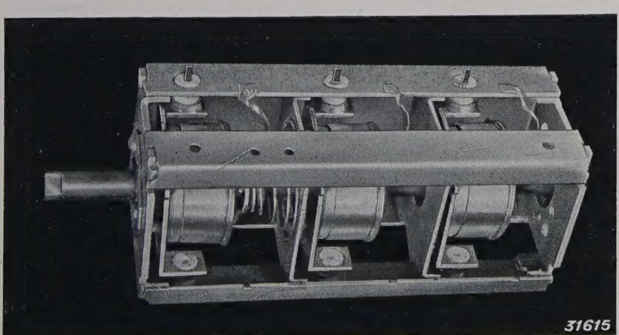

Fig. 5. Three linear action condensers combined to a single unit. The three moving sets of plates are mounted on a common shaft which is continually pressed by a strong spring (visible on the left between the first and second condensers) toward the position of maximum capacity.

The three moving sets of plates need not be insulated from each other for most connections. They are then soldered directly to the common shaft. The current connection is by means of flexible copper strips connected with the frame. Without special precautions there would also be a second current connection from the frame to the sets of plates through the shaft and the bearings, and the conductivity of this connection would vary due to the occurence of varying boundary resistances. This is undesirable in the reception of short waves. The bearings in which the condensers slide are therefore electrically insulated from the frame.

If the three moving sets of plates must be insulated from each other, as is the case for instance in special connections for short wave reception, then each set is mounted on a tube of insulation material; by covering this material with a thin

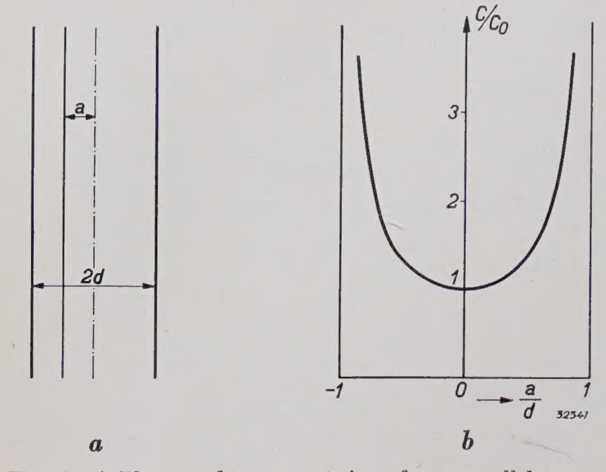

Fig. 6. a) Plate condenser consisting of two parallel connected plates with a separation of $2d$ and a movable middle plate (deviation a from the middle).
b) Variation of the capacity C upon displacement of the middle plate. If C_0 is the capacity when $a = 0$, then $C/C_0 = 1/(1 - a^2/d^2)$. By a slight displacement of the middle plate (equivalent to a slight rotation of one of the spirals of the linear action condenser) the capacity of the plate condenser (the maximum capacity of the linear action condenser) can be very accurately adjusted.

layer of metal it can be soldered, so that the plates can be firmly fastened to the shaft.

The mechanism of the push-button tuning

Fig. 7 shows the entire tuning mechanism. We shall discuss briefly the most important details.

The linear action condenser is driven in the way represented in *fig. 8*. A strong spring continually presses the shaft with the three moving condenser parts in the direction of the position for maximum capacity. The extremity of the shaft is rounded, and presses against a bar which is fastened to a shaft carrying a long swing. In front of the swing is a row of keys. When a key is pressed, the swing is moved backwards through a certain angle, and the bar pushes the condenser shaft into a definite position corresponding to the desired station. The shaft of the swing carries another bar which moves the pointer of the station scale. Hence the linear action condenser and the pointer are, as far as their position is concerned, closely coupled.

Fig. 9 is a simplified sketch of one of the push-buttons. After being pressed down the button is held by a catch in an accurately determined final position. The stop which then determines the position of the swing and hence that of the condenser consists of the point of a screw. With the help of a screw driver the listener may turn the screw farther in or out and in this way set the available push-buttons on the stations to which he most often listens.

While in the push-button system previously described [1]) the listener had to operate a separate switch in order to choose the wave-length range, the throwing of this wave-length range switch now takes place automatically upon depression of the

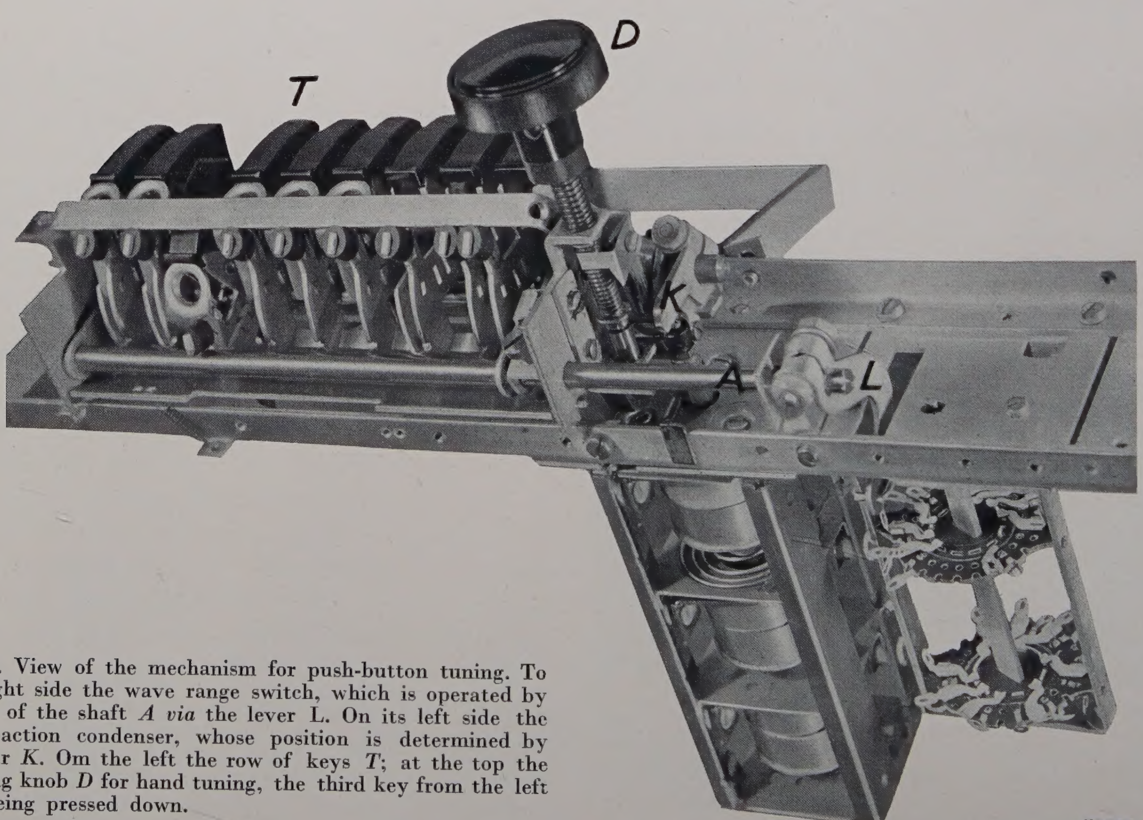

Fig. 7. View of the mechanism for push-button tuning. To the right side the wave range switch, which is operated by means of the shaft A *via* the lever L. On its left side the linear action condenser, whose position is determined by the bar K. Om the left the row of keys T; at the top the rotating knob D for hand tuning, the third key from the left side being pressed down.

station key. The mechanism by which this is accomplished is represented and explained in *fig. 10.* Part of the keys are so constructed that they can be set not only on long wave but also on medium wave. The construction is shown in *fig. 11.*

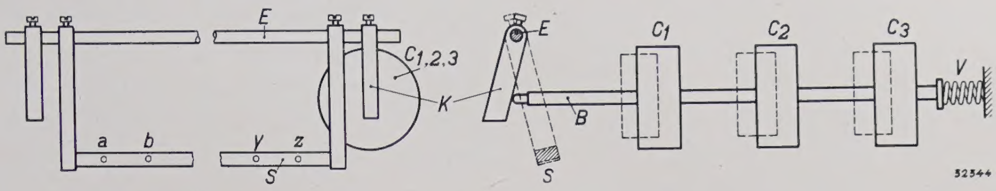

Fig. 8. The rounded end of the shaft B of the linear action condenser is pressed by a spring V against the bar K. This bar is attached to a shaft E which carries a swing S. In front of this swing is a row of push-buttons, each of which can push the swing back through a definite angle by means of a stop (at the points a, b, ..., y, z). The angle corresponds to a definite position of the condensers C_1, C_2, C_3.

In addition to the push-button tuning, hand tuning is also possible for the case where the user wishes to hear stations other than those which can be switched on by means of the keys. When hand tuning is used the wave range must first be chosen and this is again done with push-buttons which function in the same way as decribed in fig. 10, which have, however, no stop for the swing. We shall not go deeper into the mechanism of hand tuning at present.

Reproducibility of the push-button tuning

We have already stated that the desired reproducibility of the tuning is obtained if the position of the linear action condenser is determined accurately to within 0.005 mm. In order to obtain such accuracy the first requirement is that there shall be no play in the whole tuning mechanism. This is realized by causing a spring to act on every element of the mechanism, which continually draws the element in one direction and provides

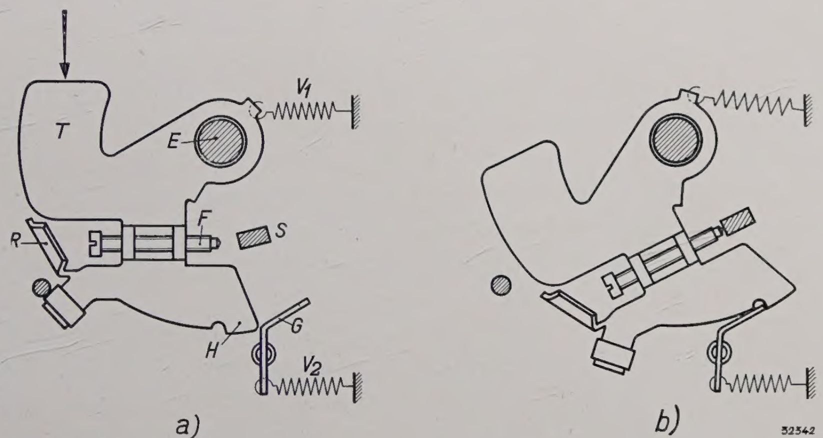

Fig. 9. Simplified sketch of the construction of one of the keys. The key turns about the axis E and is drawn into the resting position (a) by the spring V_1. When the key is pressed down in the direction of the arrow the point of the screw F pushes the swing S backwards. The final position (b) of the key is determined by the catch G. Upon pressing the key the elbow G is first turned back somewhat so that any key previously pressed is released. When the key has been pressed far enough the elbow G, drawn by the spring V_2, slides behind the projecting edge H and fastens the key in this position. By turning screw F in one direction or the other the key can be set on any station. With the key depressed the listener himself can adjust the screw with the help of a small screw driver, the point of which is introduced through an opening in the apparatus and guided to the head of the screw by the ring R.

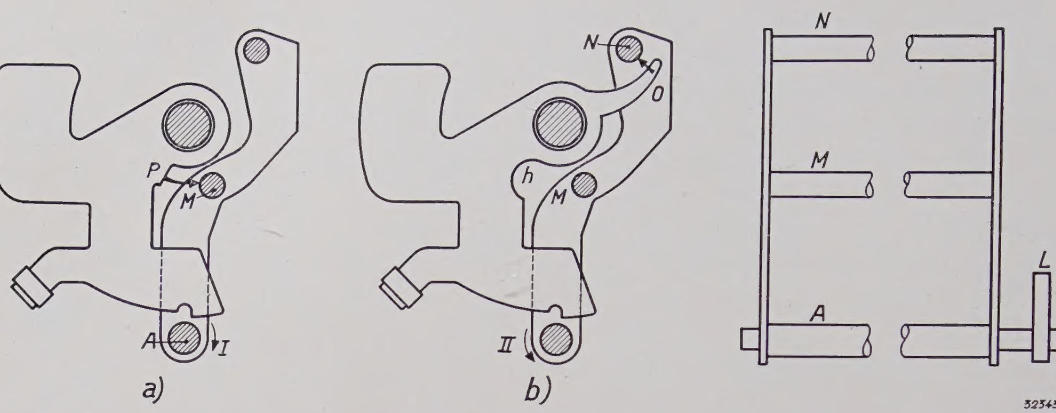

Fig. 10. Mechanism of the automatic switching from one wave range to another. The switch is driven by the shaft A through the lever L. The shaft A runs parallel to the previously mentioned swing (S in figs. 8 and 9) and bears at either end a bar in which two long pins M and N are fastened parallel to the shaft. The pin M, upon the depression of a key of the shape (a), is pushed back by the surface P, whereby by means of the shaft A the wave range switch is turned to the position for medium waves (I). When, however, a key having form (b) is pressed, the arm O pulls the pin N forward (where P was in (a) there is now a depression h in which the pin M falls), and the wave range switch is turned to the position for long waves (II).

that every stop is continually subject to a certain pressure. This is true particularly for the stop which determines the final position of the keys, for the contact between the swing and the screw point of every key and for the contact between the end of the condenser shaft and the bar, as may clearly be seen in figs. 8 and 9.

The forces exerted by the different springs cause microscopic deformations in the components of the mechanism, especially in the swing which experiences a torsion couple. These deformations may be of the order of magnitude of the above-mentioned 0.005 mm, they have, however, by themselves no unfavourable effect on the reproducibility when the condition is satisfied that the pressing of a button always causes exactly the same deformations. The deformations depend upon the forces and the stiffness of the system, therefore care must be taken that the elastic and frictional forces occurring always remain the same (the stiffness may be considered as unchanging). This means practically that there must be no friction because frictional forces depend upon the direction from which the resting position is reached, and this

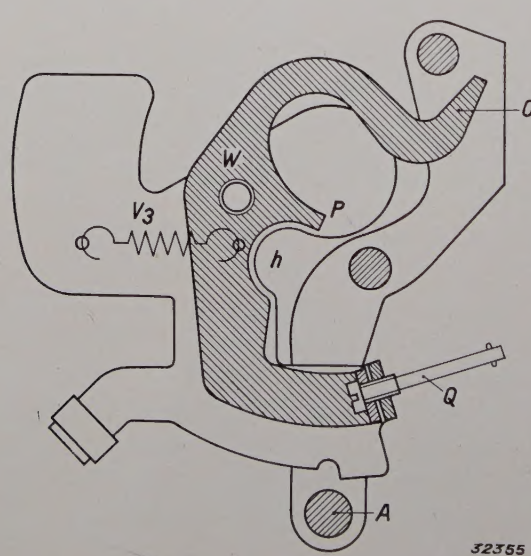

Fig. 11. A push-button which can be set not only on stations with long waves but also on medium wave stations. When the screw Q is made fast, the arm O comes into action and the key switches over to long waves (see fig. 10b). When, however, the screw is loosened the spring V_3 draws back the arm O which rotates around the axle W and at the same time the projection P fills the depression h so that the key now switches over to medium wave (see fig. 10a). The screw Q may be reached by the listener in the same way as screw F in fig. 9, without, however, the depression of the key.

direction is not under control in the pressing of a key because of the possible occurrence of slight oscillations. In the mechanism here described the frictional forces, which may occur especially in moving the condenser and the scale, are made as small as possible by careful construction of the bearings. The influence of the remaining friction is reduced to a minimum by giving the system, and particularly the swing great rigidity. This makes the deformations small and hence also reduces the influence of any variations in the same.

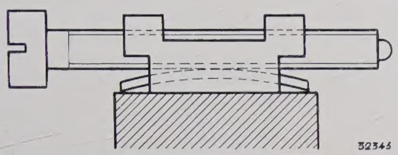

Fig. 12. Construction of the screw (F in fig. 9), which forms the stop for the swing. The screw turns in two half nuts into which it is pressed by a spring.

Torsional and bending forces, which might be transferred from the outside to the frame upon which the push-button mechanism is mounted, must of course also be carefully avoided. Since in practical cases such forces could only be transferred *via* the cabinet of the radio set and the chassis upon which the frame is fastened, this requirement was satisfied by mounting the chassis in the cabinet so that it can undergo no torsion. For this purpose the set is fastened into the cabinet at only two points and is elsewhere supported on rubber studs which can undergo a certain (plastic) deformation without transferring any force[2]).

In addition to the elastic deformations considered until now, permanent deformations must also be avoided, such as might occur at the different contact points. In order to avoid the occurrence of a gradual flattening of the material in the above-mentioned points of contact upon repeated pressing of a key (which would cause a gradual decrease in frequency switched on), the material at all these points has a hardened surface.

A quite different cause of gradual detuning upon repeated pressing of a key might be found in the turning of the screw which forms the stop for the swing. This is avoided by the construction shown in *fig. 12*; the screw turns in two half nuts into which it is pressed by a spring. The screw therefore does not turn upon receiving a shock, while on the other hand neither is it difficult to turn it when desired, so that the listener can easily readjust it when required.

Compiled by S. GRADSTEIN.

[2]) For transportation the chassis is of course fastened more securely.

RADIO SETS WITH STATION DIALS CALIBRATED FOR SHORT WAVES

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The tuning of a radio receiver in the region of short waves is much more difficult than in the normal broadcasting range because the relative difference in frequency between neighbouring stations becomes very small so that very high requirements must be made of the precision and stability of the tuning mechanism. It is explained in this article how the problems encountered in this connection are solved so that at present it is possible to fix the short wave stations on a calibrated scale with the same accuracy as that to which we are accustomed in the case of ordinary broadcasting transmitters.

In the amplification of radio signals in a receiving set a number of problems occur which are more difficult to solve the higher the frequency. Some of these problems, particularly those concerned with the receiving valves, have already been dealt with in detail in this periodical [1]). Other parts of a radio set, however, such as coils and condensers are also subject to requirements which become increasingly difficult to fulfil with increasing frequency. It is therefore natural that when broadcasting first began there was a preference for the use of long waves of the order of 1 000 m, and shorter waves only gradually began to be used when the number of stations and with it the necessary frequency range steadily increased. It was at first found impossible to use waves of less than 200 m, because shorter waves exhibit very unfavourable propagation characteristics. Later, however, it was discovered that the propagation of radio waves below the 50 m limit again becomes satisfactory. This discovery has been put into common use in recent times so that there are now regularly working broadcasting stations in a wave length range extending from 13 to 2 000 m.

Due to the increasing use of short waves, by which we understand particularly waves below about 40 m, it became desirable to make the tuning arrangements of receiving sets suitable for these short wave lengths, so that transmitters on these wave lengths could be found by moving a pointer on a station scale just as easily as transmitters of the ordinary broadcasting range (200—2 000 m).

The tuning of a receiving set

The tuning of a receiving set generally takes place by the switching over of self-inductions (choice of wave range) and then by the continuous alteration of capacities. The values which the capacities of the oscillating circuits can assume in the two extreme positions of the tuning condenser are approximately in the ratio 1 : 12, so that for a wave range which can be continuously commanded, the longest and the shortest wave lengths are in the ratio of $1 : \sqrt{12} = 1 : 3.5$. All wave lengths can then be commanded by the following division into four wave ranges, each of which can be continuously scanned by the motion of the tuning condenser.

Table I

Wave range	λ	ν
short waves I	14 - 45 m	6 700 - 23 100 kc/sec
short waves II	45 - 160 m	1 900 - 6 700 „
normal waves	160 - 560 m	550 - 1 900 „
long waves	560 - 2 000 m	150 - 550 „

The shortest permissible distance between the frequencies of two transmitters is determined by the modulation frequency which the transmitter must be able to transmit, and has been determined internationally at 9 kc/sec. The frequency difference between two neighbouring transmitters is therefore independent of the frequency itself. From this it follows that the short wave region offers space for a considerably greater number of stations than the ordinary broadcasting region. From *table I* the following *table II* may therefore be deduced:

Table II

Wave range	Width of frequency band	Number of transmitters possible
short waves I	16 400 kc/sec	1 800
short waves II	4 800 „	530
normal waves	1 300 „	145
long waves	400 „	45

By the same motion of the tuning condenser one therefore commands twelve times as many stations in the ultra short wave region as in the normal broadcasting region. In order to find a given station therefore the tuning motion must take place with twelve times the precision necessary in the normal region. If for example the required precision is set at 2 000 c/s, *i.e.* more than 1/5 of the distance between two stations, this means that the adjustment of the condenser must be reproducible with an accuracy of $1 : (5 \cdot 1\,800) \sim 0.1$ per thousand.

[1]) C. J. Bakker, Philips techn. Rev. **1**, 171, 1936. M. J. O. Strutt and A. van der Ziel, Philips techn. Rev. **3**, 104, 1938.

How is this great precision attained?

In order to attain the required precision the motion of the tuning mechanism upon passing from one station to the following must be brought about by a sufficiently great motion of the scale pointer. Furthermore the driving mechanism must be so constructed that with a given setting of the tuning knob it reproduces the position of the tuning elements with a accuracy of 0.1 per cent. Finally it is found that the required precision can only be attained when special measures are taken to provide that with a given adjustment of the set the properties of the tuned circuits do not change due to the heating up of the set when in use or to a change in temperature in the room.

The fulfilment of the first requirement is facilitated by the fact, that the stations with short waves are not spread over the whole range but are concentrated in so-called wave lengths bands, lie in the neighbourhood of the wave lengths 13, 16, 20, 30 and 50 m. This make it advisable to carry out the tuning in the following way. One first tunes in to the middle of one of the bands with fixed switch elements and then uses small variable elements in order to tune in on the desired stations. These variable elements need only to change the tuning by about 5 per cent by their entire deviation instead of by a factor 3.5, so that the adjustment of these elements may be much less precise. The variable elements need not be introduced in all the tuning circuits, but only in the most selective ones. Their position is indicated in the usual way by a pointer on a dial. The stations of a band are in this way, as it were, spread out over a separate scale. The method of tuning to be discussed in this article is indeed called band spread.

As fixed switch elements, a series of condensers can be included in the circuit instead of the variable condenser. But it is also possible to give the variable condenser a number of predetermined positions, for instances by means of a mechanism similar to that used in push-button systems. As variable elements, small variable capacities may be used which are connected in parallel with the main capacity, or small variable self-inductions in series with the main self-induction. There are a number of different possibilities for the variation of a self-induction which will be discussed in the following.

Advantages and disadvantages of various systems

An advantage of the use of a series of fixed condensers over the use of predetermined positions of the tuning condenser is that those parts which must be constructed with great precision are immovable. Another advantage is that in this sytem the influence of the temperature on the resonance frequency can be compensated very easily. This will be discussed later. On the other hand a disadvantages is the large number of switch elements; in addition to the variable element for every oscillating circuit, which must be accurately adjusted, just as many fixed condensers are needed as there are bands.

As variable element a variable condenser can more easily be constructed with the required accuracy than a variable coil. The latter has, however, the advantage that the distribution of the stations on the scales for the different bands is more favourable, as will be seen from the following consideration.

If L and C are the fixed self-induction and capacity, Δl and Δc the variable self-induction and capacity, then the tuning frequency is

$$\nu + \Delta\nu = \frac{1}{2\pi\sqrt{L\,(C+\Delta c)}} \approx \nu\left(1 - {}^1\!/_2\,\frac{\Delta c}{C}\right), \quad (1)$$

or

$$\nu + \Delta\nu = \frac{1}{2\pi\sqrt{(L+\Delta l)\,C}} \approx \nu\left(1 - {}^1\!/_2\,\frac{\Delta l}{L}\right). \quad (2)$$

We have seen from table I that the wave length bands $\lambda = 13, 16, 20, 25$ and 30 m can very well be commanded by a single coil. When this is done L is constant and

$$C = \frac{1}{4\,\pi^2\,\nu^2\,L}\,.$$

By substituting this value in (1) it follows for a variable condenser that:

$$\Delta\nu = -2\,\pi^2\,\nu^3\,L\,\Delta c, \quad . \; . \; . \quad (3)$$

while for the variable coil:

$$\Delta\nu = -\frac{\nu}{2L}\,\Delta l \quad \cdot \; \cdot \; \cdot \; \cdot \; \cdot \quad (4)$$

One would prefer to have the stations evenly spread out over the scale in all wave-length bands, and this would mean that $\Delta\nu/\Delta c$ or $\Delta\nu/\Delta l$ was independent of ν. It will be seen that this ideal is not attained in either case; the tuning with variable coil (equation (4)), however, approaches the ideal more closely than tuning with variable condenser.

A constant sensitivity of tuning, for example $\Delta\nu/\Delta C$ = const., could be attained by taking for each of the six bands another fixed coil in addition to another fixed condenser. The following condition then follows from equation (1):

$$\frac{\Delta \nu}{\Delta c} = -{}^1/_2 \frac{\nu}{C} = \text{const.},$$

and therefore:

$$C_\nu = \frac{\nu}{2 \cdot \text{const.}}\ ; \ L_\nu = \frac{1}{4\ \pi^2\ \nu^2\ C_\nu} = \frac{\text{const.}}{2\ \pi^2\ \nu^3} \quad . \quad (5)$$

From equation (5) it may be seen that when we wish to make $\Delta\nu/\Delta C$ the same for all bands the circuit capacity at short waves must be taken abnormally high. It must, indeed, contrary to its usual behaviour, increase with the frequency. From the point of view of the requirement of a constant resonance frequency this must be regarded as an advantage. The small parasitic capacities between the electrodes of the radio valves and their leads are just the ones which change sharply with temperature. When there is in addition a large fixed capacity, these changes have little influence on the tuning frequency.

We shall now describe two types of band spread which have been developed by Philips: The first with a number of fixed condensers for tuning to the middle of the bands and a variable condenser for variation within the band, and the second with a number of predetermined positions of a variable condenser for tuning to the band and a variable self-induction for variation within the band.

1. Band spread with variable condenser

The first system has been applied in a receiving set with six wave ranges distributed in the way indicated in *table III*.

Table III

I	11 - 19 m	(13 m, 16 m)
II	18 - 31 m	(20 m, 25 m)
III	30 - 54 m	(30 m, 50 m)
IV	52 - 174 m	
V	170 - 570 m	
VI	750 - 2 200 m	

It is clear that the wave ranges have been so chosen that the first three each contain two of the bands to be spread. For each band a separate fixed condenser has been chosen, while the two bands which lie in the same wave range have a common coil. In *fig. 1* the circuit is given, the text below it gives a more detailed explanation. As may be seen band spread is applied only to a single tuning circuit, namely that of the oscillator. The other oscillating circuits must therefore be sufficiently accurately tuned in the ordinary way. The adjustment of the apparatus takes place in the following way.

The desired band is at first roughly chosen with the ordinary tuning mechanism of wave switch and three coupled linear action tuning condensers.

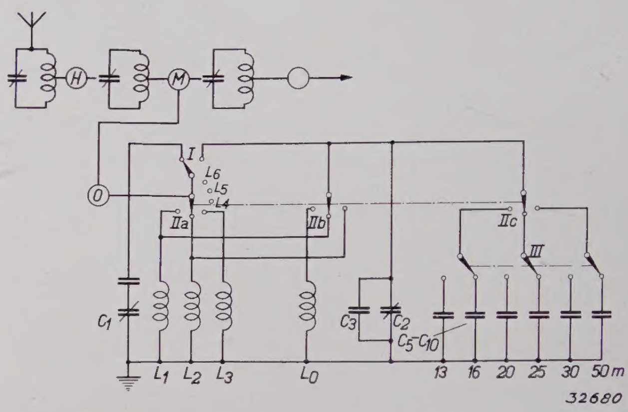

Fig. 1. Circuit for band spread: H high-frequency amplification, M mixing stage, O oscillator of mixing stage. The oscillating circuit of the oscillator can be tuned in the ordinary way with the condenser C_1 and the coils L_1 to L_3 depending on the wave switch *IIa*. When switch *I* is reversed, band spread is applied. The following serve as tuning coils for the first three wave ranges: $L_0||L_1$; $L_1||L_2$; $L_2||L_3$; while the corresponding tuning condensers are chosen by the switches *IIc* and *III*. In parallel with these condensers is the condenser C_3 for temperature compensation, and the variable condenser C_2 for the final tuning when band spread is applied.

The correctness of the adjustment is indicated by a green lamp which is lighted by means of sliding contact when the scale pointer falls on the scale division within the band in question. Band spread is then applied by drawing out a second turning knob. The linear action condenser of the oscillator circuit is hereby replaced by a larger fixed condenser, while at the same time the oscillator coil is reduced by connecting a second coil in parallel with it. By turning this second knob the variable condenser (also a linear action condenser) can now be moved and the desired station found. The position of the variable condenser is indicated by a separate pointer and a separate calibrated scale division on the tuning scale.

When the desired station has been found, its reception can often be further improved by adjusting the condensers of the first two circuits more accurately by means of the first knob, than was originally possible with the help of the green lamp.

As may be seen from fig. 1 five switches are used for the switching operations in the mechanism for band spread. Switch *I* determines whether or not band spread is applied, and is, as noted above, operated by the pulling out or pressing in of a knob. Switch *IIa* is the ordinary wave range switch; switch *IIb* serves for chosing the desired coil of the fixed oscillator circuit when band spread is applied; switch *IIc* serves in the same way for chosing the fixed condenser of that circuit. Since the last two

switches are moved together with the wave switch a certain oscillator circuit would also be put into circuit in every wave range. This is, however, not sufficient, since, as we saw above, two bands to which spread must be applied lie in a single wave range. Therefore switch *III* has been introduced to make it possible to choose between two condensers in every wave range. This is accomplished by a mechanical coupling between the switch and the turning knob for ordinary tuning. The position at which the reversal takes place is indicated in *fig. 2.* It may be seen that in each of the first three wave ranges one band has been passed while the other has not yet been reached.

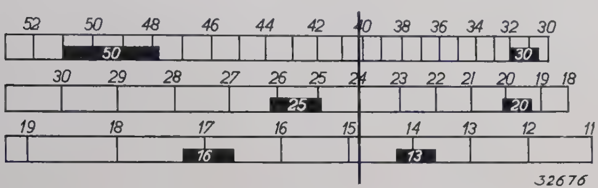

Fig. 2. When one passes from 13 to 16 m or from 20 to 25 m or from 30 to 50 m the switch *III* in fig. 1 must be reversed. This can always be done at the same position of the ordinary tuning condenser, at which point the scale indicator is at the position shown in this figure.

The constancy of the tuning

As mentioned above certain variations in the tuning frequency occur which are due mainly to the fact that different capacities in the set change with the temperature while the set is heating up. The consequence of this heating is in the first place a thermal expansion of the different elements, whereby not only the capacities become somewhat greater, but also the self-inductions of the coils. This increase in the self-induction can for the purpose of our discussion be replaced by an aequivalent increase in the capacity, *i.e.* by a variation in capacity which would cause the same change in tuning.

In addition to these variations in capacity due to thermal expansion, capacity changes may also occur due to the change of dielectric constants with the temperature. This is true particularly for parts made of glass or plastics such as the stems of radio valves, the valve sockets, switches, etc. As to the order of magnitude, an increase of the circuit capacity of about 0.1 $\mu\mu$F may be expected due to the increase in temperature.

In order to keep the effect of this change small two precautions have been taken. Firstly the fixed circuit capacity has been chosen high; its value is of course different for each band, but it is always several hundred $\mu\mu$F, so that by this means alone the variation of the capacity is already reduced to several tenths per thousand. Secondly a fixed condenser of 50 $\mu\mu$F is connected in parallel with the variable condenser. This condenser has a special ceramic dielectric whose dielectric constant decreases with increasing temperature. The capacity of this condenser (C_3 in fig. 1) therefore decreases during heating up, and compensates for the increase of other capacities. In this way the required constancy of 0.2 per cent could be attained. This means an accuracy of 0.1 per cent in the tuning frequency.

2. Band spread with correction coil

The second system of band spread was employed in a set with only four optional wave ranges which are distributed approximately as shown in table I. Band spread was applied to five bands, 13, 16, 20, 25 and 30 m, while the stations which lie in the 50 m band must be found by tuning in the ordinary way. The spread bands therefore all lie in the same wave range (short waves I).

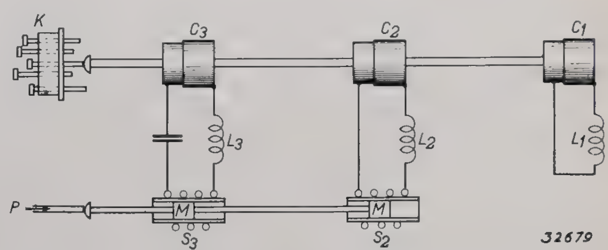

Fig. 3. Diagram of a band spread system with variable self-induction. *K* revolver head which serves to determine one of five fixed positions of the rigidly coupled linear action condensers C_1, C_2, C_3. *P* pin of the band spread mechanism by which the self-induction of the coils is altered by displacement of the iron cores *M*. The tuning of the circuit C_1L_1 (aerial circuit) is variable in this case.

The scheme of band spread is shown in *fig. 3.* By means of a revolver head *K* the triple linear action condenser can be set at five different fixed positions which correspond exactly to tuning points in the middle of the bands to be spread. This adjustment must be done with an accuracy of 0.1 per cent, which corresponds to an accuracy of 1 micron in the motion of the condenser. After the band has been chosen, tuning to the different stations on the band takes place by altering the self-inductions L_2 and L_3 in the second oscillating circuit or in the circuit of the oscillator. (In the previously described system only the oscillator circuit was sharply tuned).

[2]) Two neighbouring bands therefore have a common ratio which thus cannot be chosen exactly according to equation (5). The sensitivity in the different bands is not exactly the same but increases and decreases alternately in successive bands.

There are various possibilities for the constitution of the variable self-inductions L_2 and L_3, for example:

1) A winding is connected in series with the tuning coil, whose length is altered by means of a sliding contact (fig. 4*a*).

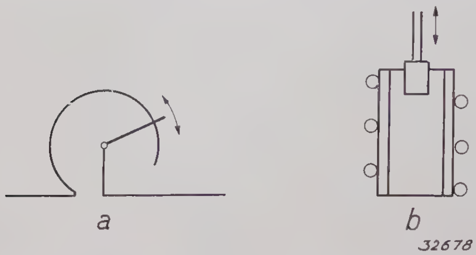

Fig. 4. Different methods of varying the self-induction of a coil. *a* Variation of the length of a winding by means of a sliding contact. *b* Variation of the self-induction of a small coil by displacement of the core of the coil. This core may be of copper in which eddy currents occur which reduce the self-induction, or of powdered iron which increases the self-induction by its magnetic induction.

2) A coil of several turns is connected in series with the tuning coil. A copper core can be inserted into the coil (fig. 4*b*). The eddy currents in the core produce a decrease in the self-induction which depends upon the position of the core.

3) Instead of the copper core a core of powdered iron is used. By its permeability this influences the self-induction in a sense opposite to that of the copper core.

The first system has the objection that sliding contacts must be introduced into the tuning circuits, which contacts may lead to noises during tuning. The second sytem is less satisfactory than the third in electrical respects because the eddy currents always cause an increase in the damping. On the other hand the third system is more difficult to construct with the necessary accuracy because it is difficult to produce iron cores with very precisely determined magnetic properties. It was found, however, that this objection could be met by a suitable construction of the driving mechanism for the motion of the core in the coil; the third system was therefore chosen.

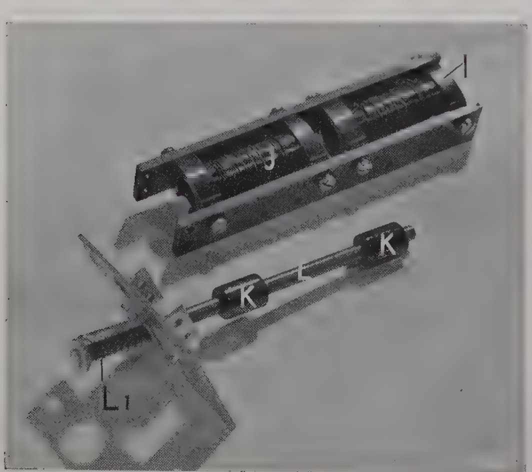

Fig. 5. Coil with variable self-induction. In two "Philite" tubes mounted in one line a screw thread of four turns has been cut. In this groove a copper wire is laid. The form of the coil is accurately fixed in this way. A rod *A* with two cores of pressed iron powder slides in the tubes.

In *fig. 5* the coil with movable iron core is reproduced; several structural particulars are given in the text below the figure.

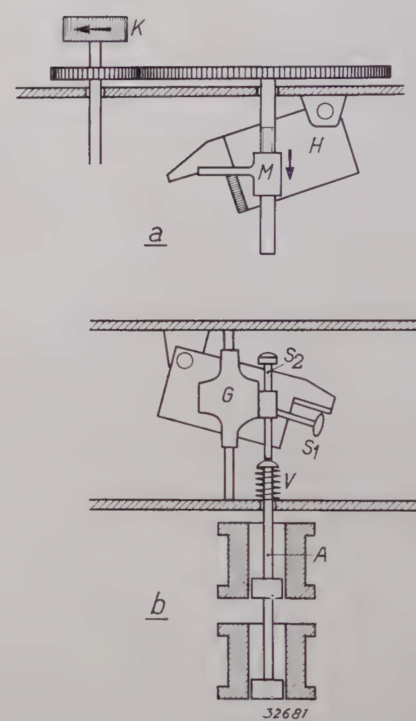

Fig. 6. The operating mechanism for band spread with variable self-induction, seen from two opposite sides. The position of the parts does not correspond exactly to that in the actual model, but has been so chosen here that all the important functional elements may be visible.

In fig. 6*a* and *b* a diagram is given of the driving mechanism. When the knob K is turned in the direction of the arrow, the nut M is also moved in that direction. In the diagram, M is shown at the position of maximum deviation in the direction of the arrow. M depresses the lever H, which is therefore also shown in its lowest position. The lever is coupled with the slide G which can be moved up and down in a vertical direction, and which by means of the screw S_2 depresses the shaft A bearing the iron core. A spring V prevents the occurrence of play in the whole mechanism.

It may be seen that the motion of the iron core can be regulated in two respects, namely in its initial position and in the magnitude of its displacement. The initial position is altered by turning

the screw S_2. The adjustment of the displacement is carried out by means of screw S_1. This screw is fastened into the slit G, while its head presses against the lever H. When it is screwed in, the effective length of the lever becomes shorter and the displacement therefore smaller. By means of this regulation of the initial position and displacement the mutual differences in the magnetic properties of the cores can be adequately compensated.

Constancy of the tuning

The variations of the tuning with the temperature may be much greater in the above-described system with variable self-induction than in the previously described system, because only small capacities are present in the oscillating circuits at short waves, so that any compensating condenser may also have only a small capacity.

If in this compensating condenser one wishes to use a dielectric with a negative temperature coefficient of the dielectric constant, one would have to construct for example a condenser which combines a low value of the capacity ($\leqslant 4$ $\mu\mu$F) with a high value of the change of capacity with temperature (up to 20×10^{-3} $\mu\mu$F °C). There exists no such dielectric.

It is, however, possible to realize such a compensating condenser by means of a construction shown in *fig. 7*. This is based on the difference in thermal expansion between the aluminium cylinder A, which forms one electrode of the condenser, and the rod C of a ceramic material which bears the other electrode B[3]).

[3]) The coefficient of expansion of aluminium is 24×10^{-6}, that of the ceramic used is 1.5×10^{-6}.

When the temperature increases, the distance between the electrodes A and B becomes greater and the capacity therefore decreases.

The temperature coefficient of the capacity can be fixed at a desired value by sliding the rod C in a lengthwise direction in the cylinder. When the capacity is increased the temperature coefficient is also increased, and its increase is proportional to the square of the capacity [4]).

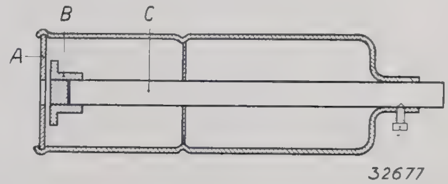

Fig. 7. Condenser for compensation of the variation of the tuning with temperature. In an aluminium cylinder A, which forms one electrode of the condenser, there is a rod C made of a ceramic material, which bears the other electrode B. Due to the difference in thermal expansion between the aluminium and the ceramic material the capacity decreases with increasing temperature.

By a correct setting of the compensating condenser the variation of the oscillator frequency can be reduced in every set to a value of a few kc/sec, this residual value is to be ascribed to the fact that different parts of the apparatus do not reach their final temperature with the same speed when the apparatus is heating up.

Compiled by G. Heller.

[4]) When d is the distance between the plates the capacity

$$C = \frac{F}{4\pi d}$$

and the variation in capacity upon change in d is

$$\Delta C = -\frac{F}{4\pi d^2}\,\Delta d = -\frac{4\pi}{F}\,C^2\,\Delta d.$$

AN ACOUSTIC SPECTROSCOPE

by J. F. SCHOUTEN.

535.33.071 : 534.44 : 778.534.45

It has already been explained in this periodical [1]) how it is possible with the help of strips of sound film to bring about light diffraction phenomena which enable one to analyse the recorded sound into its various sinusoidal components directly and comprehensively. For demonstration purposes a spectroscope has been constructed on the principle described in the article referred to which makes it possible for the observer to examine successively ten different sound spectra by the turning of a knob. *Fig. 1* is a photograph of the apparatus, and *figs. 2 - 11* are tenfold enlargements of the strips of film used and reproductions of the spectra obtained from them.

In interpreting these spectra it must be kept in mind that with the amplitude-modulated sound film here used very complicated diffraction patterns are obtained, which by their position and intensity along the horizontal axis only are a measure of the pure tone of which the total sound is composed. The distance of the lines to the centre of symmetry is in linear proportion to the frequency (in figs. 2 - 11, 1 mm corresponds to about 200 c/s), the intensity is proportional to the square of the amplitude of the individual tones.

[1]) J. F. Schouten, The diffraction of light by sound film, Philips techn. Rev. **3**, 298, 1938.

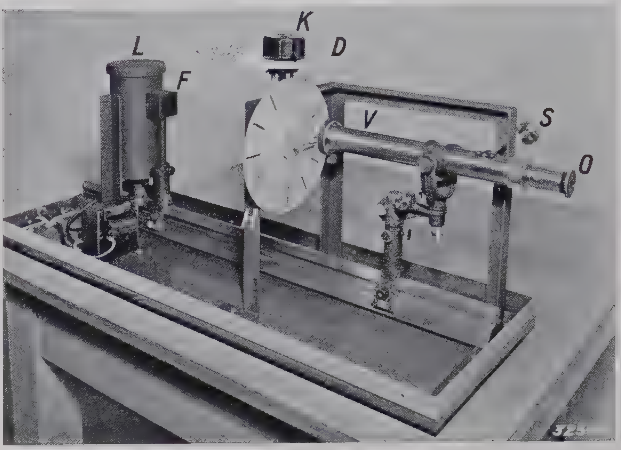

Fig. 1. The acoustic spectroscope.
A brass plate in which is a hole 30 μ in diameter is illuminated by a mercury lamp *L* (type HP 75) placed directly in front of the plate. The hole is in line with the axis of a telescope *V* with a magnification of fifteen times. In front of the objective of the telescope there is a positive lens of $2^1/_2$ dioptrics by which the image of the hole is sharply focussed at the focus of the telescope objective. The light is rendered monochromatic by a filter *F* which transmits only the light of the green mercury line ($\lambda = 5\,461$ Å). In front of the telescope is placed a rotating aluminium disc *H* which can be brought by means of the knob *K* into twelve different positions indicated on the scale *D*. By this means eleven strips of film fastened around the circumference of the disc can be brought successively into the path of the light ray. The twelfth position of the disc brings a circular opening before the objective. This position is used during the adjustment of the apparatus. When a strip of film is placed in front of the objective a diffraction pattern is obtained at the focus which can be accurately observed by means of the ocular *O* which can be adjusted with the setting screw *S*.

Fig. 2

Fig. 3

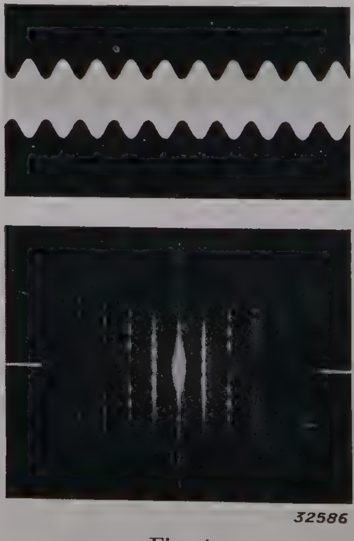

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Fig. 4

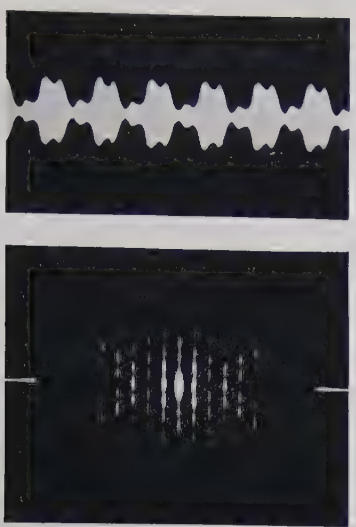

Fig. 5

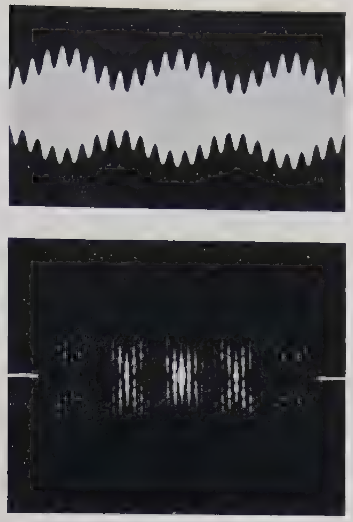

Fig. 6

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Fig. 7

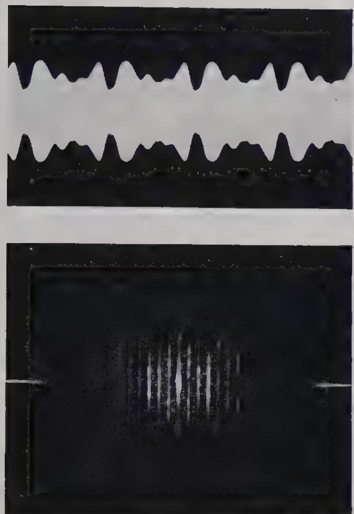

Fig. 8

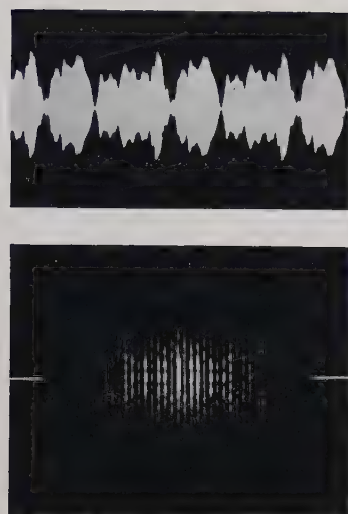

Fig. 9

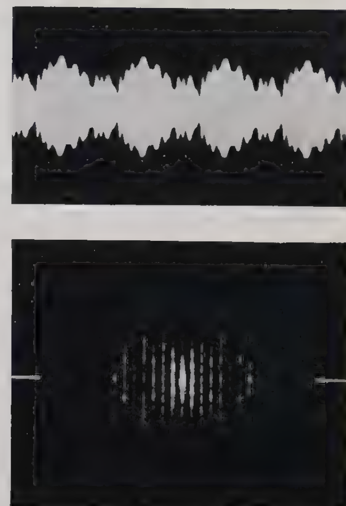

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Fig. 10

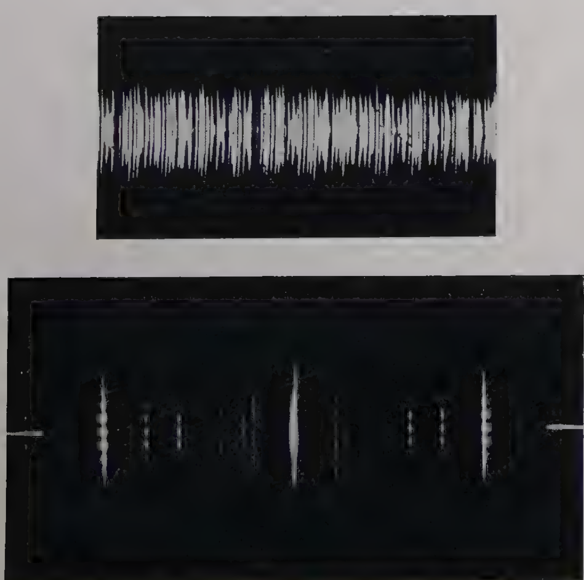

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Fig. 11

Fig. 2. *Pure tone of 23 periods.* On the horizontal axis the diffraction images of the zero and first orders only can be seen. The tone is therefore pure.

Fig. 3. *Pure tone of 350 periods.*

Fig. 4. *Nearly pure tone of 700 periods.* The second order is now also visible on the horizontal axis. The tone, therefore, contains a small proportion of second harmonic.

Fig. 5. *Tone of 400 periods with strong second harmonic.*

Fig. 6. *Sound consisting of 1 600 and 210 periods.* The 1 600 and 210 periods are visible on the horizontal axis. The diffraction pattern also contains all the combination tones which have however a zero intensity on the horizontal axis and thus do not occur in the sound.

Fig. 7. *Clarinet. Pitch G = 391 periods.* The great intensity of the third harmonic is characteristic of the sound of the clarinet, while the second harmonic is almost entirely missing.

Fig. 8. *Vowel A. Pitch G = 196 periods.* The almost complete absence of the fundamental is characteristic of this tone.

Fig. 9. *Violin. Pitch G = 196 periods.* Characteristic of the violin is the great number of harmonics and, for this low tone, the very low intensity of the fundamental.

Fig. 10. *Violin. Pitch D = 293 periods (played on the G-string).* The fundamental is now present in great intensity.

Fig. 11. *Triangle.* In the case of all the sounds reproduced until now the components were aequidistant, which is shown by the fact that all the partial frequencies were multiples of a fundamental. In the case of the triangle this is not the case, the partials are not harmonics.

MEASUREMENTS CARRIED OUT ON ROAD LIGHTING SYSTEMS ALREADY INSTALLED

by P. J. BOUMA.

535.24 : 628.971.6

In the first part of this article measurements on road lighting installations are described (horizontal and vertical intensity of illumination, distribution of brightness, reflection coefficients, visibility). The illumination of the road between Vught and Tilburg is chosen as an example and studied in detail. In the second part a number of conclusions are drawn, on the basis of all the material collected, about *a*) the visibility with different kinds of light, with different kinds of road surface, with different degrees of moisture of the road surface, etc.; *b*) the degree of shininess (specular reflection) of the various road surfaces in dry as well as wet states; *c*) average reflection coefficients of the various road surfaces, etc. In the third part certain items are chosen from the experimental material for the purpose of illustrating certain peculiarities of vision on artificially lighted roads.

Introduction

Several times in this periodical general guiding principles have been given for the illumination of roads with gas discharge lamps from the point of view of the properties of the eye. In connection with this it seemed desirable to collect certain data on the state of illumination which is actually obtained in the case of road lighting systems with gas discharge lamps which have already been installed. In addition to technical data, such as the power consumed per running meter, we shall in the first place attempt to determine how the light falls upon the road. For this purpose a knowledge of the horizontal and vertical intensity of illumination is required. In order to judge the quality of the installation, however, it is more important to know how the lighted road surface reflects the light in the direction of the eye of the observer. For this purpose the distribution of brightness on the road surface must be determined. The relation between intensity of illumination and brightness is given by the reflective properties of the road surface, which are in turn strongly influenced by the amount of moisture on the road.

As an important criterion of the quality of road illumination we mention finally the visibility, especially that at the most favourable and least favourable spots on the road surface.

The quantities mentioned are determined, partly by calculation and partly by measurement for a number of systems already installed [1]).

Description of the measurements

In the following we shall give all the numerical data for one of the installations studied: namely the sodium lighting system of the road Vught - Tilburg, which may be considered as representative of the average sodium lighting system. The lamps are mounted in a zig-zag pattern as indicated in *fig. 1*. The height of the lamps is 8 meters. Sodium lamps of the type SO 650 (105 watts, 6 500 lumens) placed in enamelled reflectors, type SORA [2]), are used. The axis of the lamp is horizontal to the ground and perpendicular to the direction of the road. The power consumed is 3.24 kilowatts per kilometer, and an amount of light of 200 lumens per running meter is provided. The road surface consists of a fairly light-coloured kind of asphalt. The installation was studied in the dry state.

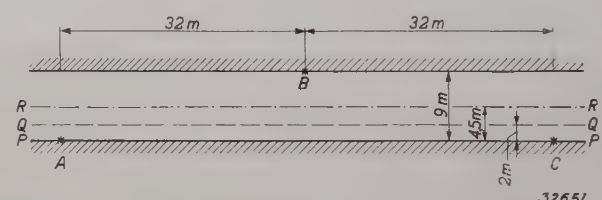

Fig. 1. Road from Vught to Tilburg. Sketch of the lighting installation. *A*, *B*, *C* represent light sources. *RR* is the middle of the road. *QQ* is the middle of the right hand half.

Horizontal intensity of illumination

The horizontal intensity of illumination at different spots on the road surface was calculated from the curves for light distribution measured in the laboratory from the combination of sodium lamp and reflector. The result is given in *fig. 2*. *A* and *B* represent two lamps. The highest and the lowest values are 15.9 and 2.1 lux, respectively, the average value is 5.5 lux. Several control measurements were carried out on the road itself. It was found that the calculated values were actually

[1]) The measurements were carried out by the author with the collaboration of Mssrs. Bergmans and Keitz, while the last mentioned took upon himself the photography and the measuring of the photographs.

[2]) See also the article: Sodium lamps, Philips techn. Rev. 2, 353, 1937, figs. 2 and 10.

attained [3]). The measurements were carried out as close as possible to the ground (about 6 cm).

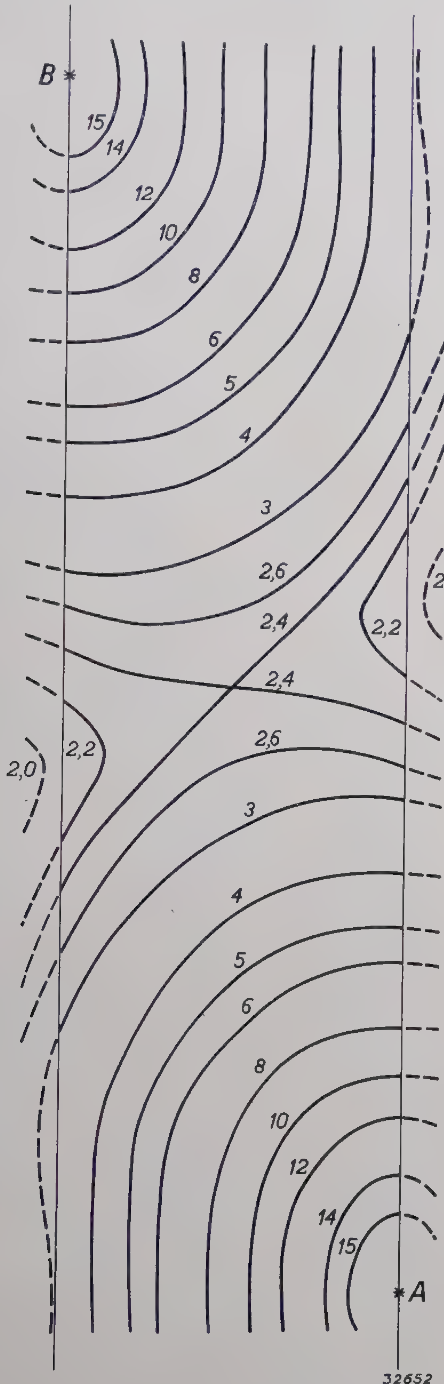

Fig. 2. Road Vught-Tilburg. Horizontal intensity of illumination calculated in lux. A and B represent light sources.

Vertical intensity of illumination

The variation of the vertical intensity of illumination in the direction of length of the road was calculated along the three lines given in fig. 1: PP along one edge directly under the lamps, QQ along the middle of the right-hand half, and RR along the middle of the road, assuming that the window of the luxmeter was standing perpendicular to the direction of length of the road, and facing left in fig. 1. *Fig. 3* gives the results. Each curve shows two maxima; the first is due to lamp A, the second to lamp B. As one approaches more nearly the middle of the road, the height of the maxima becomes more and more nearly equal; from considerations of symmetry it is immediately clear that in the case of curve R the two maxima must be equal. *Fig. 4* gives a comparison between the values calculated (for the line PP) and the values measured on the road. The measured points are in general found to coincide satisfactorily with the calculated curve. From this the conclusion may be drawn that the influence of illumination on the vertical intensity of the light reflected by the road, which influence was neglected in the calculation, is actually very small. In the case of a road surface like the one in question this was indeed to be expected.

Average coefficient of reflection

If by the term "reflection coefficient of a road surface" we wished to describe a numerical factor which would enable us to calculate immediately the brightness occuring at any spot on the road surface from the horizontal intensity of illumination on the road, it must immediately be stated that such a universal numerical factor does not exist. The relation between intensity of illumination and brightness is, in the case of most road surfaces, very dependent on the direction of the incident light and on the direction from which we view the surface [4]).

In order, however, to give some idea of whether we are concerned with a "dark" or a "light" road surface, we shall introduce the concept of an "average reflection coefficient". By this term we mean the reflection coefficient which the road surface has when the light is incident perpendicularly and the direction of viewing makes an angle of 45° with the normal [5]). This average reflection coefficient is easily measured by laying a number of different dull grey pieces of paper under one of the sources of light, and observing them at

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[3]) Due to the failure to clean the reflectors and exchange the lamps promptly, values lower than those claculated were found in the case of various installations.

[4]) *Cf.* for instance J. Bergmans, The Reflection of Light by Road Surfaces, Dissertation, Delft 1938, and the literature there mentioned. See also Philips techn. Rev. **3**, 321, 1938.

[5]) More precisely defined: the value which the quantity $\varrho = B/E\ 100\ \pi$ assumes under these circumstances, when ϱ is expressed in per cent, the brightness B in c.p./sq.m, the intensity of illumination E in lux.

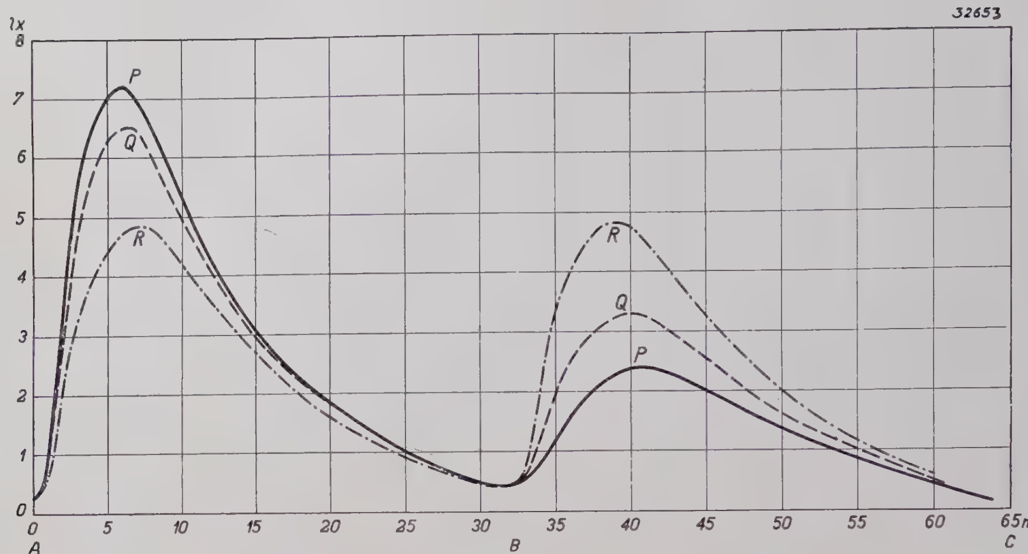

Fig. 3. Road Vught-Tilburg. Vertical intensity of illumination (calculated).
Curve P: along the edge of the road (PP in fig. 1).
Curve Q: along the middle of the right hand half (QQ in fig. 1).
Curve R: along the middle of the road (RR in fig. 1).
The window of the luxmeter is considered perpendicular to the length of the road and facing left: A, B and C represent the same light sources as in fig. 1.

angle of 45° in order to see which is of the same brightness as the road surface. For dry road surfaces the values found give a direct impression of how bright or how dark the different road surfaces will appear in the daytime with a clouded sky. For the road chosen as example here the average reflection coefficient $\varrho = 11\%$, which is a fairly high value for asphalt roads.

Distribution of brightness over the road surface

As we have already mentioned, a knowledge of the average reflection coefficient is inadequate for the calculation of the distribution of brightness from the intensities of illumination on the road. The distribution of brightness must be measured separately, and in our case it was done photographically.

For this purpose a photograph of the road was made at the height of the eye on a rapid panchromatic plate upon which a horizontal strip was covered and thus unexposed. Later on in the laboratory an exposure was made on this strip with the same kind of light and the same exposure time of a light box covered with a stepped density wedge ("Stufen Graukeil"), *i.e.* a glass plate divided into a number of sections with accurately known light

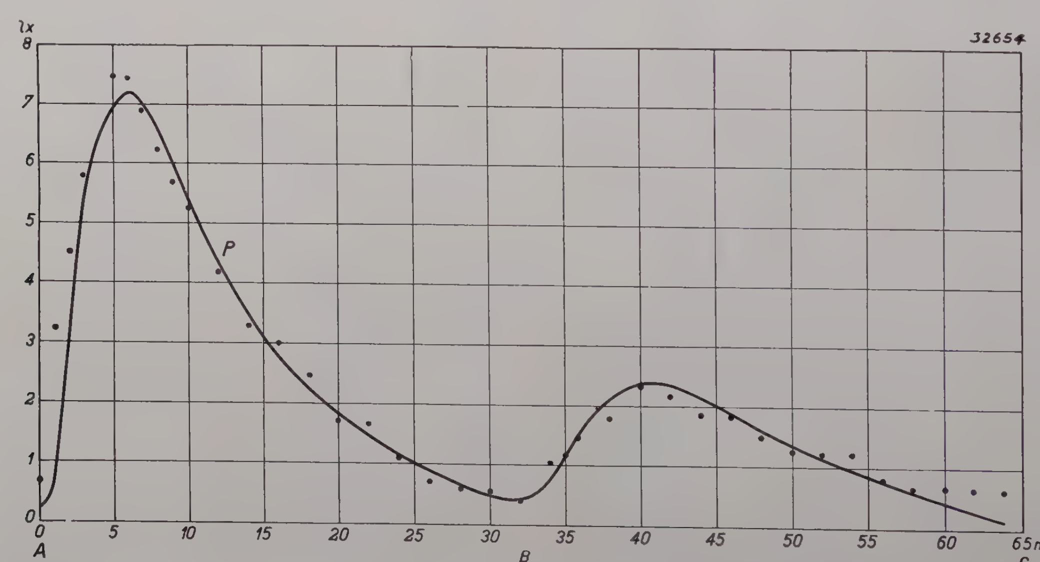

Fig. 4. Road Vught-Tilburg. Vertical intensity of illumination. The curve represents the calculated value (curve P of fig. 3), the points the measured values.

Fig. 5. Photograph of the road Vught-Tilburg used for the measurement of the distribution of brightness given in fig. 6. The observer (the camera) is situated on the line QQ in fig. 1 at such a point that the black stripes bound the part of the road lying between 23 and 63 m from the observer. In this section the distribution of brightness was measured. At the top may be seen the density marks used.

transmissions. By comparing the blackening of the different parts of the photograph of the road with that of the sections of known brightness, we can determine the brightness of the road surface.

Fig. 5 is a copy of the negative used for the Vught - Tilburg road with the density marks at the top of the photograph. *Fig. 6* gives the distribution of brightness on the road surface deduced from the photograph. Since the brightnesses to be measured do not vary by more than a factor 15, and the density curve of the material used has an almost linear form over a much greater range, we were able to include the whole range of brightnesses in a single photograph.

In the measurement of the plate the average blackening of circular spots which have a diameter of 0.1 mm on the negative was determined photoelectrically. These spots would be observed on the road within a visual angle of more than 2 minutes, so that practically all the details which can be observed by the eye can also be recognized on the photograph.

If one now compares the distribution of brightness found (fig. 6) with the distribution of intensity of illumination (fig. 2) the following points of difference become obvious:

1) The regions of great brightness near the lamps have a much more linearly extended form than the regions with high intensity of illumination. In the perspective picture of the road this means: the regions of high intensity of illumination would appear to the eye as narrow stripes perpendicular to the length of the road; the regions with great brightness would be seen as much less narrow spots.
2) The greatest brightness is not directly beneath the lamps, but closer to the observer; with more distant lamps this effect is more pronounced than with those closer to the observer. The two

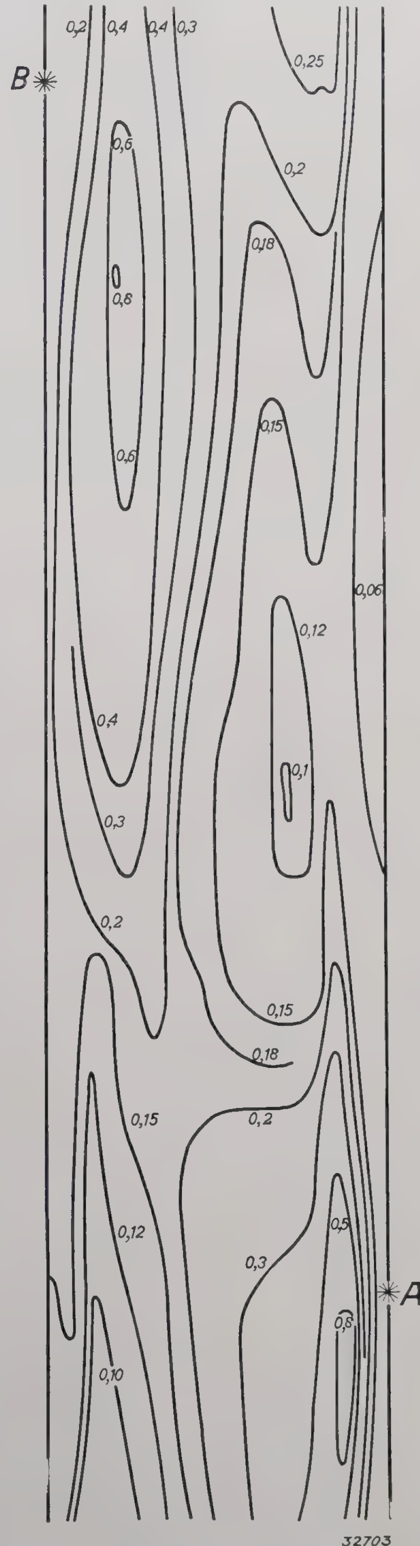

Fig. 6. Road Vught-Tilburg. Distribution of brightness over the road surface (in c.p./sq.m).

differences mentioned occur in extreme forms when the road is wet.

3) Fig. 6 shows many small irregularities due to the lack of homogeneity of the road surface; with diffuse illumination in the daytime spots can be observed in almost every road surface. In fig. 6 also it may be seen that the fact is confirmed that a pedestrian almost always appears dark against the background of the road surface. If he is wearing an overcoat with a reflection coefficient of 4 per cent (most overcoats are much darker) he will exhibit no greater brightness than 0.09 c.p./m² even at the point of highest vertical intensity of illumination, and he will therefore appear dark against practically the whole road surface.

The complete distribution of brightness was not determined for all the installations studied; in a number of cases we confined ourselves to determining the highest and lowest brightnesses in a visual way.

Visibility measurements

The visibility measurements were carried out with the visibility meter described elsewhere in the periodical [6]). This instrument enables one to observe simultaneously a large part of the road surface and a number of test objects (round spots of different brightnesses). By finding out which of the spots is just barely visible against the background of the road surface we can determine the contrast visible on the road. In the case of the installation in question the contrast was 16.4 per cent for the most favourable part of the road surface and 33.3 per cent for the least favourable part. Both values agree very well with the average values obtained for sodium lighting installations.

General conclusions from all the experimental material

Visibility with different kinds of light [7])

Visibility measurements were carried out on 24 sodium lighting systems, 6 mercury lighting systems and 3 mixed lighting systems, all in the dry state, and finally on 7 sodium lighting systems in a moist state [8]). *Table I* gives the average results, namely the visibility Z (as the lowest contrast observable in per cent) at the most favourable spot, the visibility z at the least favourable spot, the average power installed (kW/km) and the average number of lumens per meter of the installation.

Table I

Kind of light	Condition of the road	Z %	z %	kW/km	lm/m
Sodium	dry	17.2	31.2	3.30	200
Mercury	dry	26.0	35.4	6.43	217
Mixed light	dry	21.4	35.3	10.82	233
Sodium	damp	24.1	44.3	3.42	211

The installations which led to these averages were in most respects comparable. All of them had shielded lamps. The height from the ground and distance apart varied relatively little. The number of lumens per meter for the different kinds of light is also almost the same (217 ± 8%), so that the difference in results obtained with the visibility meter must be ascribed almost entirely to the specific properties of the kind of light used.

It may be seen that the results for the sodium lighting installations are considerably better than those for the other kinds of light, not only with respect to the value of Z but also with respect to that of z.

When we recall that it has been found in previous experiments that for safe rapid traffic it is generally necessary that contrasts of 25 - 30 per cent should be easily observable on the greatest portion of the road, it will be clear that only the sodium lighting systems satisfy this requirement well, while in the case of the other kinds of light the situation is often quite doubtful. It may furthermore be seen that as soon as the road becomes slightly damp the visibility decreases considerably: z becomes very much worse due to the occurrence of dark patches, while, in spite of the occurence of parts with quite a high brightness, Z also becomes worse due to the greater lack of uniformity in the distribution of brightness.

Visibility measurements were also carried out on roads lighted by ordinary electric lamps, gas lamps or less carefully shielded gas discharge lamps. Since however there are in this country (the Netherlands) too few of such installations which are comparable in other respects to the cases used for the compilation of Table I, it is at present difficult to give a true comparison.

Visibility and average reflection coefficient ϱ

The average reflection coefficient ϱ indicates whether we are concerned with a dark or a light surface. For 8 concrete road surfaces we found an

[6]) See Philips techn. Rev. **1**, 353, 1936.

[7]) For the number of observers, individual differences etc. see the end of this article.

[8]) On the degree of moisture see in the following "The shininess of damp and wet roads".

average ϱ = 23 per cent, for 11 granite block surfaces, average ϱ = 9 per cent, for 6 asphalt road surfaces average ϱ = 8 per cent. Among the granite block pavements the greatest variation of reflection coefficient was found (5-12%); the highest average reflection coefficient observed was that of a concrete road surface (29%).

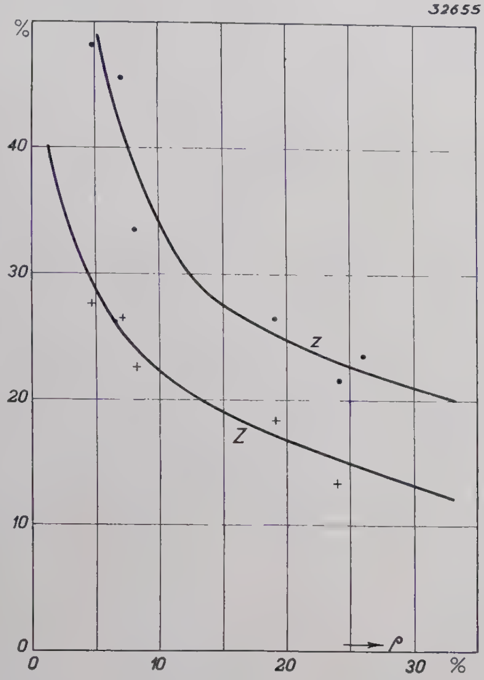

Fig. 7. Visibility as a function of average reflection coefficient of the road surface expressed as the smallest observable contrast in per cent. Z is the contrast at the most favourable, z that at the least favourable spot on the road surface. The measurements were carried out on different parts of the Brussels-Antwerp road.

In general it may be said that with similar installations and with a dry and not too unusual kind of road surface, the higher the value of ϱ the higher the average level of brightness, and the better the visibility. This statement could be tested in the case of the road between Brussels and Antwerp the whole of which is lighted with the same kind of sodium lamps, but which has a number of sections which differ as to the nature of the road surface.

In *fig. 7* the visibility on this road is drawn as a function of the average reflection coefficient of the road surface (z at the least, Z at the most favourable spot).

It may be seen that especially with reflection coefficients below 10 per cent the visibility becomes rapidly worse with decreasing reflection coefficient. The fact that this actually does illustrate the effect of the influence of the average level of brightness on the visibility may be seen from *fig. 8* which gives the visibility Z as a function of the intensity of illumination E, measured on a concrete road while darkness was falling and without artificial illumination. This curve is quite similar in shape to those of fig. 7.

The "shine" of a road in dry state

If the road were absolutely "dull", in other words if it were perfectly diffusely reflecting so that the reflection coefficient was independent of the direction of incidence and observation, one could calculate the brightness directly from the intensity of illumination of a given point on the surface by means of the following:

$$B = \frac{E\,\varrho}{100\,\pi}$$

(B brightness in c.p/sq.m; E horizontal intensity of illumination in lux; ϱ average reflection coefficient in percent). One could in particular calculate the greatest brightness existing, B_M from the highest intensity of illumination, E_M:

$$B_M = \frac{\varrho E_M}{100\,\pi} \quad \ldots\ldots\ldots \quad (1)$$

Actually the road is not absolutely dull, so that equation (1) must be replaced by:

$$B_M = K\,\frac{\varrho E_M}{100\,\pi}.$$

K is here a quantity dependent upon the reflective properties of the road surface and on the nature of the lighting system, and it gives an idea as to the magnitude of the differences between the bright-

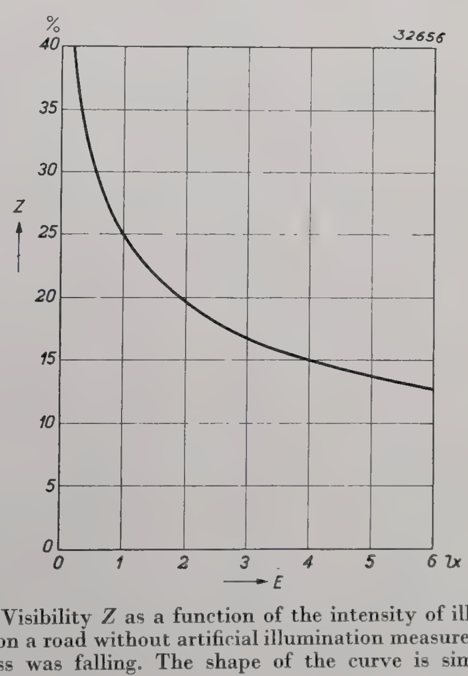

Fig. 8. Visibility Z as a function of the intensity of illumination E on a road without artificial illumination measured while darkness was falling. The shape of the curve is similar to that in fig. 7.

nesses actually occurring and the brightnesses which would be expected with a diffusely reflecting road surface. For a perfectly diffusely reflecting road surface $K = 1$.

In general the deviations of the reflective properties of a road surface from those of a diffusely reflecting surface consists in the fact that the road surface reflects more strongly in the direction of the observer rays which are incident almost horizontally, usually at the expense of the amount of light which is reflected from other directions. The first result of this is the appearance of the phenomenon that the region of greatest brightness no longer coincides with that of greatest intensity of illumination (see figs. 2 and 6).

In the case of very shiny road surfaces (for instance when wet) spots with great brightness will occur. K is considerably greater than unity. In the case of dull surfaces one may encounter the phenomenon that while the spot with greatest brightness has been displaced to a spot with a lower value of E, the reflective capacity at that spot has not however yet increased so much that a higher value of B_M occurs than would be expected from equation (1). Under these circumstances therefore K may assume values which are smaller than unity. In the case of the system of lighting commonly used in the Netherlands (concentrating armature with a cut-off angle of about $2 \times 75°$), this is the case for most concrete roads.

For the most commonly occurring road surfaces the following average values of K were found: concrete: $K = 0.72$; granite blocks: $K = 1.12$; alsphalt: $K = 1.48$.

It must be noted that the quantity K must be used with some care. It will depend partly upon the nature of the lighting system as to the extent to which the special reflective properties of the road surface will give rise to the appearance of great brightnesses, so that K is actually a quantity which characterizes the state of a given road surface when a given lighting system is applied, in other words K gives us an impression of the brightness phenomena actually occurring. With entirely different lighting systems (for example where much light is emitted at small angles to the horizon) different values of K will be found. The values given here are valid for the most commonly used system in the Netherlands (the light source radiates practically no light at angles greater than 75° with the vertical).

Another quantity which is closely dependent upon the degree of shininess of the road surface is the ratio $B_M : B_m$ of the highest and the lowest brightnesses occurring: with very shiny road surfaces this ratio will assume high values. It is however clear that this quantity is even more dependent than K on other factors, such as the lighting system, width of the road, etc. As average values for the installations measured (several installations of a strongly diverging type were omitted) we found for: concrete $B_M : B_m = 4.8$; granite blocks $B_M : B_m = 8.1$; asphalt $B_M : B_m = 10.4$. The shinier the road the more K and $B_M : B_m$ increase. An attempt was therefore made to discover any possible simple relation between the two quantities. In *fig. 9* the two quantities have been plotted against each other. The simple points refer to installations with different dry road surfaces, the points surrounded by circles refer to the above mentioned averages for the three types of road surfaces, the crosses to several installations under moist conditions. Except for a rather wide scattering of the points, which was to be expected, it may be seen that there exists a fairly close connection between the two factors. $B_M : B_m$ increases more rapidly than K, which is to be understood: when

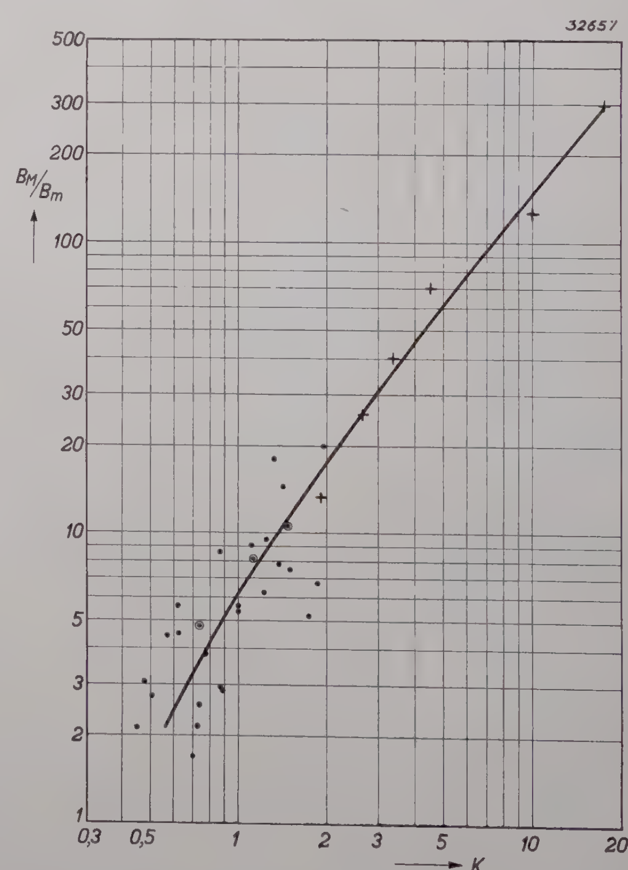

Fig. 9. Correlation between the two quantities $B_M : B_m$ and K, both of which give an idea of the degree of shininess of the road.
● Different installations, dry condition.
⊙ Average values for concrete, granite block and asphalt surfaces.
\+ Different installations, damp condition.

the road surface becomes more shiny B_M increases, but at the same time B_m decreases.

The "shininess" of damp and wet roads

As soon as the road surface becomes damp, it becomes more shiny, K and B_M/B_m increase sharply. It is difficult to express the degree of dampness in figures. We have therefore confined ourselves to an estimation of the degree of dampness according to the following scale:

1. Dry
2. Slightly damp (occurs for example as the result of mist)
3. Damp
4. Very damp
5. Wet (not during rain, there is as yet no formation of puddles)
6. During moderate rain (formation of puddles)
7. During heavy rain (inundation of the road surface)

The data given until now about damp road surfaces have referred exclusively to the conditions 1 to 4.

Data for all these conditions of dampness are given in *table II*. It must be noted that all values for concrete road surfaces refer to the same installation (the Boschdijk in Eindhoven), while the data for asphalt are for different installations (Eindhoven, Haarlem and surroundings).

Table II

Condition of dampness	B_M/B_m		K	
	concrete	asphalt	concrete	asphalt
1	4,4	7,6	0,60	1,50
2		13,4		1,90
3	26	40	2,7	3,4
4	70	126	4,5	10
4 - 5		300		17
5			12 - 96	34 - 220
6			65 - 740	

Two values are given for K for the conditions 5 and 6 (wet and very wet). The first is valid when we do not take into consideration the brightness of the light spot caused by the nearest light source (which is at a distance of less than 30 m), the second is for the case when this light source is taken into consideration. The fact that one sees the image of the light source itself reflected on the road surface in the case of the nearest lamp thus has an enormous influence. This is made impossible in the case of more distant lamps by their shields. With installations having unshielded sources of light the first values are almost as high as the second. For a concrete road surface with such an installation measured in condition 6. $K = 410 - 660$.

Fig. 10 illustrates the increase in K and $B_M : B_m$ with the degree of dampness for concrete (curve 1) and for asphalt (curve *2*). It is clear that the difference between the two kinds of road surface remains even at high degrees of dampness. This difference may be expected to disappear for the quantity $B_M : B_m$ in condition 7 (flooding).

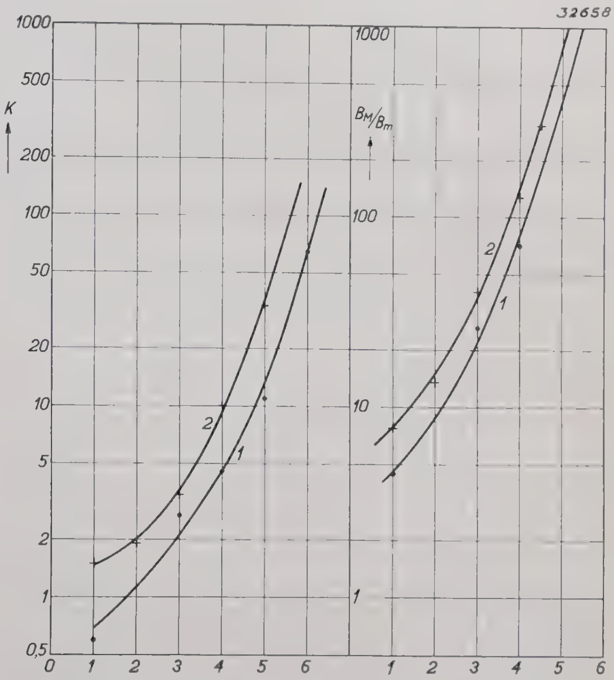

Fig. 10. The quantities $B_M : B_m$ and K (both of which give an idea of the degree of shininess of the road) with increasing degree of dampness: *1* for concrete; *2* for asphalt. See text for the significance of the numbers *1 –6*.

Visibility on damp and wet roads

During rain (conditions 6-7) measurements with the visibility meter are of little use: a large part of the road surface is so black that one can no longer observe even the darkest points on the meter. It is also out of the question that small objects would appear dark against the lighter road under such circumstances. Vision on thoroughly wet roads takes place in a different way, and is based on the following considerations:

1) The edge of the road is often indicated by the light spots on the road; illuminated trees and the like may be useful here.
2) Objects on the road often cast a shadow across such a light spot.
3) Objects on the road are more brightly illuminated by car headlights than the dark road surface.

As to the visibility at the other degrees of damp-

ness (1 - 5), we have collected the following among other data:

Table III

Condition of dampness	Concrete		Asphalt	
	Z (%)	z (%)	Z (%)	z (%)
1 (dry)	8	26	15	26
2			24	43
3			28	48
4	26	48		
5 (wet)	34	62	36	

The visibility is again expressed as the lowest observable contrast in per cent, Z for the most favourable and z for the least favourable spot on the road surface.

It is clear that the visibility at the most favourable spot decreases rapidly in spite of the increasing brightness as the road becomes wetter, while with really wet roads the visibility at the most unfavourable spot is practically no longer measurable.

Several special cases

In conclusion we shall present several instructive points in connection with visibility measurements.

Visibility and density of traffic

Dense traffic on the road, when numerous points of light are visible in the distance, and even without the disturbing influence of undimmed automobile headlights and poorly directed bicycle lamps, has a very unfavourable influence on visibility. All the results given until now were obtained at times when there was very little traffic on the road (usually between 1 and 3 o'clock in the morning). *Table IV* gives a comparison of the visibility on several dry roads chosen at random, with and without dense traffic.

Table IV

Road	Z		z	
	with dense traffic	without dense traffic	with dense traffic	without dense traffic
a	$29^1/_2$	$16^1/_2$	39	$25^1/_2$
b	44	$12^1/_2$	55	$32^1/_2$
c	25	$14^1/_2$		21
d	$28^1/_2$	10		$21^1/_2$

Visibility and non-uniform distribution of brightness

Great local brightness does not always produce better visibility. The truth of this statement for the case of wet roads has already been shown above (see Table III). In the case of dry roads also we encountered several typical cases in which great local brightness is of no advantage.

The first case was encountered on a sodium lighted part of the road Brussels—Antwerp, where the road is divided into two separate halves, one of which has a concrete surface and the other is paved with dark but quite shiny granite blocks. The general level of brightness was considerably lower on the granite-paved part, the maximum brightness was however almost the same in both cases. In spite of the latter fact the visibility at the most favourable spot on the granite paved half was much poorer than that on the concrete half (27 against 14 per cent): the non-uniformity of the distribution of brightness on the shiny granite renders the visibility poorer. An even more telling example was encountered near Haarlem where two halves of a slightly damp asphalt road (condition 2) were lighted in the same way with sodium lamps, the only difference between the two sides being the employment of different types of fixtures which made the distribution of brightness different. *Table V* gives some of the results of measurements on this road.

Table V

	1st part	2nd part
Greatest brightness B_M	0.47	2.45
Least brightness B_m	0.062	0.044
Visibility Z	13^5	19^5
Visibility z	36	42

It is obvious that z is more unfavourable on the second — less uniform — part. It is however somewhat surprising that the visibility at the brightest place on the second part is also more unfavourable than for the first part: the lack of uniformity in the distribution of brightness has such a disturbing effect that the advantage of the greater local brightness is entirely destroyed. It must be noted that the brightest spots on the second part of the road were of somewhat smaller area than on the first part. This striking phenomenon was observed by three independent observers.

Visibility and individual differences

In order to make the subjective factor, which is characteristic of every visibility measurement, as small as possible, the results obtained by different observers were included in the material discussed in the foregoing. Three observers usually worked together; in many cases previous measurements by other observers were available. These

observers had often used visibility meters with a slightly different calibration.

In order to be able to compare all these measurements with confidence, they must be corrected for individual differences of observers and instruments. This was done by making a table of all the cases where the measurements were carried out by several persons or with different instruments. From this table a fixed correction could be determined for every combination of observer and visibility meter, which correction brought all the measurements to the same average level. In almost all cases the correction amounted to only 1 or 2 points of the visibility meter.

After this fixed correction had been applied the measurements of the various observers showed satisfactory agreement in the case of every installation, so that we could take their average without hesitation and could at the same time draw the conclusion that the phenomena described in this article were valid for all the observers who contributed.

THE EFFICIENCY OF LOUD SPEAKERS

by J. de BOER. 621.395.623.742

A discussion is given of the distribution of the energy supplied in an electrodynamic loud speaker, and an aequivalent circuit is devised for the purpose of studying this energy distribution and at the same time the efficiency of the loud speaker. An estimation of the efficiency for a practical example indicates the reason why a value of only a few per cent is obtained for the efficiency. The fundamental limitations which prevent the attainment of appreciably higher efficiencies are explained.

Considered from the point of view of energy the loud speaker, that for instance built into a radio set, plays the part of a transformer which converts electrical energy into acoustic energy. This point of view is of practical importance when it is desired to know the energy which must be delivered by the amplifier in order that the loud speaker connected with it may produce sound of a certain intensity. Just as in the case of transformers of other types such as power transformers, in this case also one may speak of the efficiency of the energy conversion in the loud speaker, and one means in this case the fraction of the (electrical) energy supplied, which is converted into useful (acoustic) energy. In the case of good loud speakers a value of several per cent is found for the acoustic efficiency. Compared with other methods of sound excitation this value is not low: Jeans (in his book "Science and Music") states that a church organ converts only 0.13 per cent of the energy supplied into sound. The "efficiency" of a pianist seems to be about 0.2 per cent. In technology, however, especially in the case of "transformers" in the narrower sense of the term, one is accustomed to efficiency values of more than 90 per cent. Why does the energy conversion in the loud speaker compare so unfavourably with these values? What becomes of the rest of the energy supplied? What factors influence the efficiency? These are a few questions which we shall consider in this article. We shall confine ourselves to loud speakers of the electrodynamic type, which are the most important for practical cases since they give the best quality of reproduction.

Energy balance of an electrodynamic loud speaker

Fig. 1 is a photograph of an electrodynamic loud speaker system, while *fig. 2* is a diagram of a cross section of such a system. In the cylindrical air gap between the pole pieces of a magnet is a moving coil to which is fastened a conical membrane. When currents modulated according to the vibrations of speech or music are sent through the coil, it moves in the same rhythm, and the cone, which moves with it, communicates the motion to the air. If one considers the different ways in which the electrical energy supplied can be taken up in the system the following conception is reached.

The coil has a certain electrical resistance by which energy is dissipated in the form of heat [1]).

[1]) We shall neglect the self-induction of the coil. In order to prevent the self-induction from becoming large due to the fact that the lines of force of the coil would pass through the iron of the pole piece over the greater part of their course, a copper ring is often placed around the inner and outer circumferences of the cylindrical air gap. When this measure is taken the self-induction only becomes appreciable at frequencies of the order of 10 000 c/sec.

When moving the mass of the coil and cone has a certain kinetic (wattless) energy; potential energy (also wattless) is taken up in the elastic suspension of the system, and energy is dissipated by friction in this suspension. Finally energy is also given off to the air, and we have seen in a former article [2]) that this energy consists of two components: a wattless energy which can be given back to the radiator by the air, and the useful acoustic energy [3]).

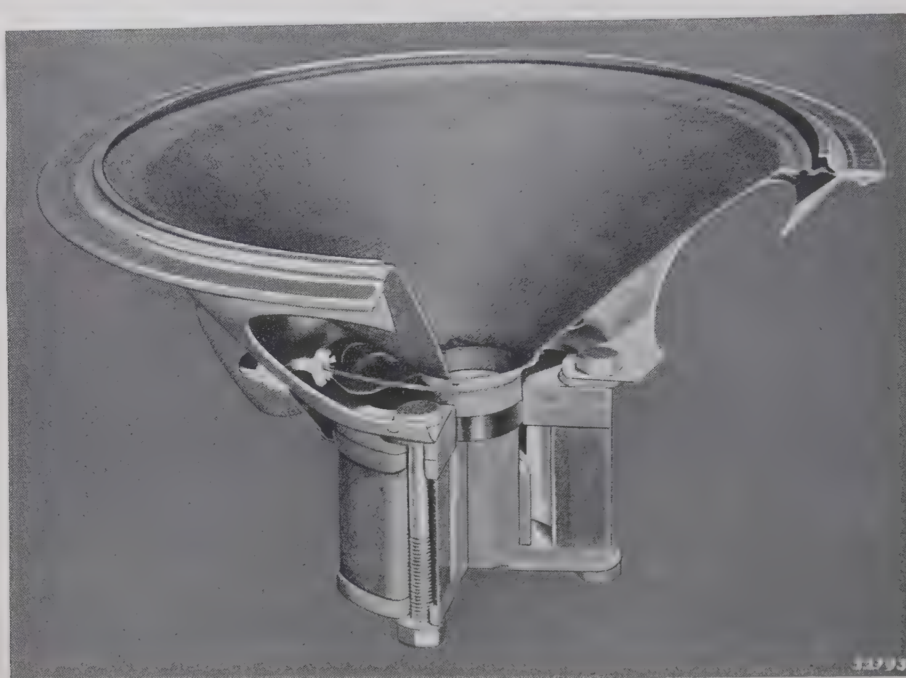

Fig. 1. Photograph of an electrodynamic loud speaker system (the system is cut open).

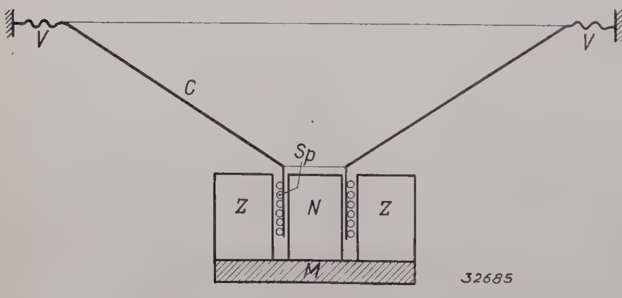

Fig. 2. Diagram of an electrodynamic loud speaker. In the air gap between the pole pieces N and S of the magnet M (pole S is in the form of a ring) is the moving coil Sp to which is fastened the cone C suspended from springs V. The currents modulated by the sound are conducted through Sp.

Introduction of an equivalent circuit

In order to obtain an idea of the distribution of the energy supplied over the various energy reservoirs we shall introduce an equivalent electrical circuit for the loud speaker, *i.e.* a circuit in which each of the reservoirs mentioned is represented by an electrical element which takes up the same energy as the corresponding reservoir in the original system at any frequency of the voltage acting on the circuit. In *figs. 3a* and *b* the mechanical models are first indicated for

a) the moving mechanical system. This consists of the mass M_M of coil and cone together which is fastened to a spring with the stiffness S. When the mass is moved at a velocity v it

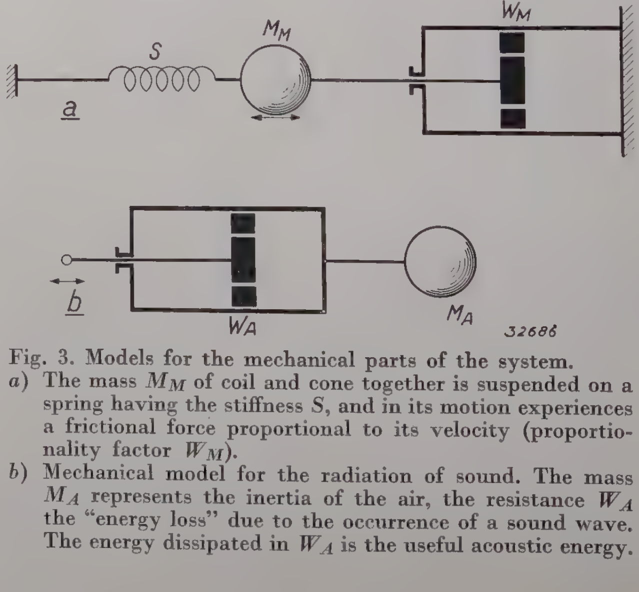

Fig. 3. Models for the mechanical parts of the system.
a) The mass M_M of coil and cone together is suspended on a spring having the stiffness S, and in its motion experiences a frictional force proportional to its velocity (proportionality factor W_M).
b) Mechanical model for the radiation of sound. The mass M_A represents the inertia of the air, the resistance W_A the "energy loss" due to the occurrence of a sound wave. The energy dissipated in W_A is the useful acoustic energy.

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[2]) A. Th. van Urk and R. Vermeulen; The radiation of sound, Philips techn. Rev. 4, 225, 1939.

[3]) We assume that the cone is placed in a large baffle, so that no potential energy can be taken up by a tangential motion of the air; see the article cited in footnote [2]). The loud speaker radiates toward both sides of the baffle.

experiences a frictional resistance $W_M \cdot v$.
b) the air. This model is derived in the article cited [2]). The acoustic energy radiated corresponds to the energy dissipated in the mechanical resistance W_A when an acceleration is given to the mass M_A. The kinetic energy of the mass M_A is the (wattless) energy which is taken up in the flow of air.

These two models can, with the electrical resistance R_E of the coil, be combined to give the entirely electrical circuit given in *fig. 4*, where it must be assumed that:

$$\left.\begin{aligned} L_M &= H^2 l^2 \frac{1}{S} \quad , \\ C_M &= \frac{1}{H^2 l^2} M_M \quad , \\ R_M &= H^2 l^2 \frac{1}{W_M} \quad , \end{aligned}\right\} \quad \ldots\ldots \quad (1)$$

$$\left.\begin{aligned} C_A &= \frac{1}{H^2 l^2} M_A \quad , \\ R_A &= H^2 l^2 \frac{1}{W_A} \quad . \end{aligned}\right\} \quad \ldots\ldots \quad (2)$$

H stands for the magnetic field (assumed to be homogeneous) in the air gap, and l for the length of the wire of the coil.

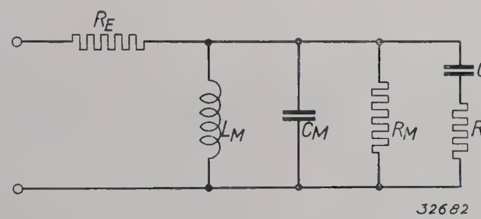

Fig. 4. Entirely electrical equivalent circuit, in which each of the energy reservoirs in the loud speaker system (figs. 3a) and b)) is represented by an element, and in which the energy distribution among the elements is identical with that among the reservoirs in question.

Justification of the equivalent circuit

The fact that the equivalent circuit satisfies the requirement made of it can be shown in the following way. We assume that the system executes an harmonic vibration. For the motion of the electrodynamic system (fig. 2) two equations are valid. The first, electrical, equation expresses the fact that the voltage V across the ends of the coil is equal to the sum of the voltage drop along the resistance R_E and of the counter EMF which is induced in the coil in its motion at the velocity v:

$$V = R_E \cdot i + H\,l\,v. \quad \ldots\ldots \quad (3)$$

where i is the current in the coil. The second, mechanical, equation expresses the fact that the motive force $H\,l\,i$ on the coil is equal to the reaction of the mechanical system:

$$H\,l\,i = Z_M \cdot v. \quad \ldots\ldots \quad (4)$$

Z_M is here the (complex) mechanical impedance, *i.e.* the relation between the force and the velocity of movement of the mechanical system.

From equations (3) and (4), by the elimination of v,

$$V = i\left(R_E + H^2 l^2 \frac{1}{Z_M}\right). \quad \ldots\ldots \quad (5)$$

Both the sytems represented in fig. 3 contribute to the mechanical impedance Z_M.

For the mechanical impedance Z_{M_1} of the system a one finds with the help of the equations of motion:

$$Z_{M_1} = \frac{K_1}{v} = W_M + j\omega M_M + \frac{S}{j\omega}.$$

For the mechanical impedance Z_{M_2} of the air (system b) in fig. 3) one finds [4]):

$$\frac{1}{Z_{M_2}} = \frac{v}{K_2} = \frac{1}{W_A} + \frac{1}{j\omega M_A}.$$

The total force on the system is the sum of the forces K_1 and K_2, and therefore the total mechanical impedance is:

$$Z_M = \frac{K_1 + K_2}{v} = W_M + j\omega M_M + \frac{S}{j\omega} + \frac{1}{\dfrac{1}{W_A} + \dfrac{1}{j\omega M_A}}.$$

This is substituted in a somewhat different form in equation (5):

$$\frac{V}{i} = R_E + \frac{1}{\left[\dfrac{1}{\frac{H^2l^2}{W_M}} + \dfrac{1}{\frac{H^2l^2}{j\omega M_M}} + \dfrac{1}{\frac{H^2l^2 j\omega}{S}}\right] + \dfrac{1}{\frac{H^2l^2}{W_A} + \frac{H^2l^2}{j\omega M_A}}} \quad \ldots\ldots \quad (6)$$

The denominator of the second member has the form of the reciprocal of the impedance of the connection in parallel of four elements: a self-induction L_M, a capacity C_M and a resistance R_M which are defined by equation (1) and an element which consists of a resistance R_A and a capacity C_A defined by equation (2) connected in series. Formula (6) expresses the fact that this combination of four elements in parallel is connected in series with the resistance R_E. This is, however, exactly what is represented in the equivalent circuit, the

[4]) See equation (13) on page 288 of the article cited in footnote [2]).

circuit is therefore a faithful representation of the system as far as the impedances are concerned and therefore also as far as the energy distribution is concerned.

Application of the equivalent circuit

Since the resistance R_A in fig. 4 represents the equivalent of the mechanical resistance W_A of the air in fig. 3*b*, in applying a voltage to the circuit of fig. 4, we must consider the energy, which is dissipated in the resistance R_A as the useful energy given off. The ratio between this energy and the total energy taken up in the circuit is the efficiency. This ratio is determined by the current distribution in the circuit; this distribution, however, clearly depends upon the frequency. For a certain frequency a resonance occurs between the self-induction L_M and the capacity $C_M + C_A$ (the resistance R_A in series with C_A may here be neglected, since at the resonance frequency $R_A \ll 1/\omega\, C_A$). As we shall see this gives rise to a maximum in the efficiency of the loud speaker at the resonance frequency: $\nu_0 = 1/2\,\pi \sqrt{L_M\,(C_M + C_A)}$. No advantage can be taken of this maximum in practical cases, because a "straight" characteristic is required of the loud speaker for the sake of the quality of reproduction, *i.e.* a constant variation of the energy radiated as a function of the frequency when the energy supply is constant. Such a characteristic is obtained approximately by making the resonance frequency of the loud speaker as low as possible, so that practically the whole range of frequencies to be reproduced acoustically lies above the resonance frequency.

Estimation of the acoustic efficiency in a practical case

On the basis of the equivalent circuit we shall now examine the efficiency obtained at different frequencies for a practical case. In *table I* the quantities required for the composition of the circuit for the case of a given loud speaker (Philips radio loud speaker 9 602) are given.

The electrical resistance R_E, the stiffness S of the suspension, the mass M_M of coil and cone together and the frictional resistance W_M are determined by measurement. The mass M_A and the resistance W_A of the model of fig. 3*b* for the radiation may be derived theoretically by idealizing the loud speaker membrane, for example to a pulsating sphere. In the previously cited article [2]) this calculation has been carried out with the following result (see equation (14) of that article):

Table I

Data for a radio loud speaker (type 9 602)

	Actual quantities	Corresponding elements in the equivalent circuit
	$H = 7\,000$ oersted $l = 523$ cm	Transformation factor $H^2 l^2 = 13.4 \times 10^{12}$ dyne
measured	$R_E = 4$ Ohm	$R_E = 4$ Ohm
	$S = 1{,}44 \cdot 10^6\ \frac{\text{Dyn}}{\text{cm}}$	$\frac{H^2 l^2}{S} = L_M = 9{,}3$ mH
	$M_M = 5{,}2$ g	$\frac{M_M}{H^2 l^2} = C_M = 0{,}39$ mF
	$W_M = 260\ \frac{\text{Dyn sec}}{\text{cm}}$	$\frac{H^2 l^2}{W_M} = R_M = 52$ Ohm
Derived theoretically for a pulsating sphere, radius $a = 6$ cm	$M_A = 3{,}5$ g	$\frac{M_A}{H^2 l^2} = C_A = 0{,}26$ mF
	$W_A = 1{,}9 \cdot 10^4\ \frac{\text{Dyn sec}}{\text{cm}}$	$\frac{H^2 l^2}{W_A} = R_A = 0{,}7$ Ohm

In the conversion of the mechanical into electrical quantities according to equations (1) and (2) by means of the "transformation factor" $H^2 l^2$ it must be noted that in the measurement of H in oersted and l in cm the electrical quantities are obtained in absolute electromagnetic units. In order to express the quantities in the practical units the factor $H^2 l^2$ must be multiplied by 10^{-9}.

$$\left.\begin{aligned} M_A &= 4\,\pi\,a^3\,\varrho\ , \\ W_A &= 4\,\pi\,a^2\,\varrho\,c\ . \end{aligned}\right\} \quad \dots\dots \quad (7)$$

where s is the radius of the sphere, ϱ the density of the air and c the velocity of propagation of the sound in air. For the loud speaker in question the radius of the equivalent pulsating sphere may be taken as 6 cm (*i.e.* about 0,7 times the radius of the opening of the cone). The values of M_A and W_A given in the table then follow. These values, and the following remarks in general, are, however, valid only at those frequencies at which the cone of the loud speaker vibrates as a whole, which is the case up to frequencies of 1000 c/s.

In *fig. 5* may be seen the equivalent circuit with the values of the different elements indicated. As an example we shall determine the efficiency at a frequency of 160 c/s, *i.e.* when $\omega = 1000$. At this frequency the impedances of the various elements have the values given in *table II*.

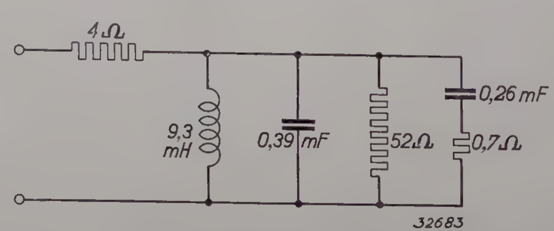

Fig. 5. The equivalent circuit for a practical case.

Table II

Impedances occurring in the equivalent circuit at $\omega/2\pi = 160$ c/s.

R_E	=	4	Ohm
ωL_M	=	9,3	,,
$1/\omega C_M$	=	2,6	,,
R_M	=	52	,,
$1/\omega C_A$	=	4	,,
R_A	=	0,7	,,

The shunts ωL_M and R_M may be neglected here compared with $1/\omega C_M$. For a rough estimation of the current distribution we shall also neglect R_A compared with the impedance $1/\omega C_A$ in series with it. The fraction $2.6/(4 + 2.6) = 0.4$ of the total current i through R_E then passes through the elements $C_A R_A$. In R_A the energy $(0.4\ i)^2 R_A$ is dissipated, in R_E the energy $i^2 R_E$. The efficiency η_a is therefore the following:

$$\eta_a = \frac{(0{,}4\ i)^2 \cdot 0{,}7}{i^2 \cdot 4 + (0{,}4\, i)^2 \cdot 0{,}7} = 2{,}7\%.$$

From this estimation the reasons why the efficiency is so low become evident. In the first place it is due to the fact that R_E is considerably larger than R_A. If the full current passed through R_A the efficiency would still only amount to $0.7/4 = 17$ per cent. In the second place the shunt formed by C_M takes up a high wattless current which also flows through R_E and there causes considerable loss. Turning from theory to reality, this means that a large force is necessary to start the motion of the coil and the cone which of itself requires no energy. This force is obtained by a large current through the coil which develops considerable Joule heat in the resistance of the coil.

When in resonance the motion of the mechanical system requires only enough force the overcome friction, the coil then need not conduct wattless current for this purpose, and the efficiency of the loud speaker is considerably higher. In the example in question the resonance frequency lies at 65 c/s. At this frequency one finds an efficiency of 25 per cent. Passing on to still lower frequencies, the impedance ωL_M in the shunt becomes the most important one. This impedance falls with decreasing value of ω, while the impedance $1/\omega C_A$ rises. The fraction of the total current passing through R_A therefore decreases approximately with the square of ω. The efficiency, which is proportional to the square of this fraction, therefore decreases with the fourth power of the frequency at frequencies lower than the resonance frequency. This is the reason why the resonance frequency of a loud speaker is made as low as possible.

Above the resonance frequency we may, as was done above in the estimation of the efficiency for a given frequency, neglect the impedance ωL_M and R_M compared with $1/\omega C_M$. We therefore actually make use of the simplified equivalent circuit shown in *fig. 6*. The current distribution in the two

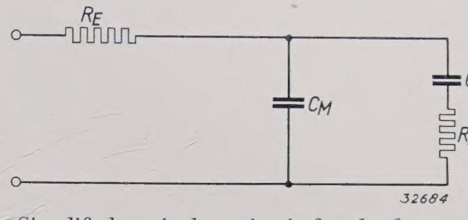

Fig. 6. Simplified equivalent circuit for the frequency range above the resonance frequency.

branches in parallel is independent of the frequency when R_A is small compared with $1/\omega C_A$. Under this condition, therefore, the efficiency is constant, which means at the same time that the characteristic of the loud speaker has the desired straight form. At high frequencies, however, R_A gradually becomes comparable to $1/\omega C_A$; with increasing frequency the impedance of the shunt C_M then falls more rapidly than that of the circuit $C_A R_A$, the current distribution becomes less favourable and the efficiency falls. In the example discussed, from the condition that $R_A = 1/\omega C_A$, a value in round

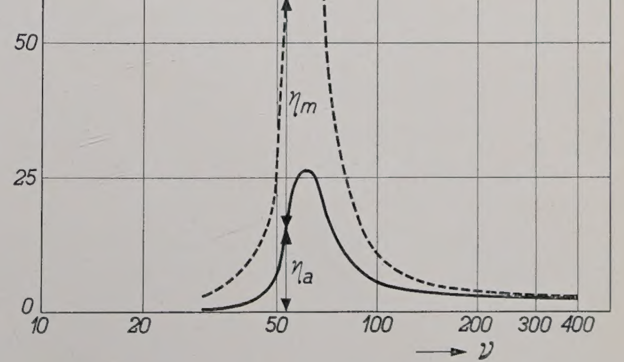

Fig. 7. Variation of the acoustic efficiency η_a (full line curve), of the loud speaker used as practical example, as a function of the frequency ν in c/s. The distance between the dotted curve and the line $\eta_a = 100\%$ gives the electrical efficiency η_e (the fraction of the energy dissipated in R_E). The distance between the two curves at every point along the ν-axis gives the fraction η_m of the energy supplied which is dissipated in the mechanical resistance (W_M in fig. 3a).

numbers of $\omega/2\pi$ = 900 c/s is found for the frequency where the fall in efficiency begins. In practical cases, however, new resonances begin to be noticeable just in this region, which are due to modes of vibration of the cone in which it no longer moves as a whole.

By making use of these resonances a fairly constant efficiency (straight characteristic) can be obtained up to considerably higher frequencies.

The precise calculation of the acoustic efficiency η_a from the data of table I gives the curve shown in *fig. 7*. The distance between the broken line curve and the line η_a = 100% gives the "electrical efficiency" η_e, *i.e.* the fraction of the energy supplied which is dissipated in the electrical resistance R_E. The distance between the two curves is then the remainder of the energy which is dissipated in the frictional resistance of the mechanical system.

The fundamental limitations of the efficiency

It has already been pointed out that the low efficiency is due in the first place to the fact that R_E in the equivalent circuit is unsatisfactorily large. One might therefore attempt to make the resistance R_E of the coil smaller in order to obtain a higher efficiency. The resistance R_E is given by:

$$R_E = \frac{l}{q \cdot \sigma}, \quad \cdot \cdot \cdot \cdot \cdot \cdot \quad (8)$$

where l is the length, q the area of the cross section of the wire and σ the conductivity of the material of the wire. The following holds for the mass of the winding:

$$m_s = l\, q\, \varrho_s, \quad \cdot \cdot \cdot \cdot \cdot \cdot \quad (9)$$

where ϱ is the specific weight of the wire material. This mass contributes in the equivalent circuit an important amount to the capacity C_M which is of course derived from the mass m_s and the mass m_c of the cone in the following way:

$$C_M = \frac{M_M}{H^2 l^2} = \frac{m_s + m_c}{H^2 l^2}.$$

If C_M is divided into two capacities: $C_s = m_s/H^2 l^2$ and $C_c = m_c/H^2 l^2$, it follows from (8) and (9) that

$$R_E \cdot C_s = \frac{\varrho_s}{H^2 \sigma}. \quad \cdot \cdot \cdot \cdot \cdot \quad (10)$$

With a given field strength and kind of material, therefore, a reduction of R_E, for example by increasing the diameter of the wire while keeping its length the same, is accompanied by an increase in C_M. This means that when we attempt to improve the efficiency of the loud speaker in the manner described by decreasing the energy dissipated in R_E, the current distribution in the circuit is affected in such a way that the efficiency becomes l o w e r. When the optimum existing between these two opposing influences has been found, then according to equation (10) further improvement can only be obtained by increasing the strength of the magnetic field or by the choice of another material for the coil.

In the method described for the reduction of R_E the volume of the windings of the coil and at the same time that of the necessary air gap increases. This means that for the same field strength H a greater magnetic energy is needed (the latter is given by H^2 times the volume of the air gap), this means therefore a greater quantity of the magnet steel. If for the sake of these practical considerations the condition is made that the air gap is not be altered in an attempt to decrease R_E, *i.e.* that the product $l.q.$ must remain constant, then instead of equation (10) a still stricter limitation holds; the length and diameter of the wire now have absolutely no effect on the efficiency, According to (2) and (8) R_A/R_E = const. $l.q.$ therefore, upon simultaneous alteration of l and q under the condition $l.q$ = const., the ratio R_A/R_E remains unaltered, while at the same time the current distribution in the circuit also remains unaltered, since the impedances R_A, R_M, $j\omega$, L_M, $1/j\omega C_M$ and $1/j\omega C_A$ all vary in the same way (proportionally with l^2).

In the above we began with an attempt to improve the efficiency by decreasing R_E and arrived in our attempt at a fundamental limitation. Going back to the above estimation and the reasons therein discovered for the low value of the efficiency, an attempt might now be made to improve the efficiency by increasing R_A (*i.e.* by decreasing the resistance W_A in the acoustic model fig. 3*b*). This would indeed lead to the desired result if the, relatively small, capacity C_A were not present, *i.e.* if the occurrence of the sound were not connected with the acceleration of the mass of air which unfortunately is very easily set in motion. Due to the presence of this capacity an opposition of different influences is again encountered which makes any essential improvement of the efficiency impossible. According to equations (2) and (7) R_A is given by:

$$R_A = \frac{H^2 l^2}{4\pi a^2 \varrho c}. \quad \cdot \cdot \cdot \cdot \cdot \quad (11)$$

It is obvious that R_A can be increased by reducing the radius of the cone which is proportional

to the radius a of the equivalent pulsating sphere. Then, however, the capacity C_A becomes smaller, since, according to (2) and (7):

$$C_A = \frac{4\pi a^3 \varrho}{H^2 l^2}, \quad \cdots\cdots \quad (12)$$

and the current distribution in the circuit (fig. 6) is influenced in such a way that the improvement in the efficiency is again opposed. This influence is indeed partially compensated by the fact that the part C_c of the capacity C_M in the shunt falls; C_c is of course proportional to the mass of the cone, which also becomes smaller upon a decrease in the radius. Since the efficiency depends in different ways upon the three quantities mentioned, R_A, C_A and C_c, and since these quantities in turn again vary with different powers of a, it is impossible to foresee in this qualitative consideration just what effect a change in a will finally produce upon the efficiency. Further consideration shows that when the relation between R_E and C_s is kept at the above-mentioned optimum value (which depends upon C_c and C_A and therefore upon a!), the efficiency increases slowly with the radius a. We have, however, seen that in order to obtain a straight characteristic for the loud speaker it is necessary that the impedance of the two branches connected in parallel in fig. 6 vary in the same way throughout a large frequency range, so that the current distributions remains constant. Because of this the condition $R_A \ll 1/aC_A$ had to be satisfied. For the limiting frequency ω_1 of the straight part of the characteristic we may therefore set up the equation

$$R_A\, C_A = \frac{1}{\omega_1} \quad \cdots\cdots \quad (13)$$

Upon combination of (11) and (12) it follows that

$$R_A\, C_A = \frac{a}{c} \quad \cdots\cdots \quad (14)$$

and it therefore follows that an increase in the diameter of the cone would lead to a shortening of the straight part of the frequencies characteristic. Since the efficiency varies only slowly with the radius a, a limit is soon reached in this direction.

The only method of improving the efficiency without encountering a fundamental limitation is to increase the intensity of the magnetic field H while keeping all the other quantities including the volume of the coil constant. This method was already mentioned in the discussion of equation (10). This can also be perceived immediately upon the following consideration: the "transformation factor" $H^2 l^2$ in equations (1) and (2) increases with the square of H; all impedances in the circuit in series with R_E (fig. 4) are increased in proportion. The current distribution (and therefore the frequency characteristic) remains unaltered, but R_A becomes larger compared with R_E. In modern loud speakers the magnetic field is indeed made as strong as is practically possible.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1412: F. A. Kröger: Luminescence and absorption of ZnS-MnS mixed crystals (Physica, **6**, 369-379, April, 1939).

Mixed crystals of zinc sulphide and manganese sulphide obtained by activating zinc sulphide phosphors with manganese exhibit luminescence in two bands with maxima at 5 850 Å and approximately 6 200 Å, the latter probably being the still-unexplained red band of zinc sulphide phosphors. The emission of phosphors activated with manganese may be ascribed to two electronic transitions in the bivalent manganese ion, which also occur on absorption. In addition to the absorption bands of pure ZnS, mixed crystals of zinc and manganese sulphide also exhibit a third absorption region consisting of a system of bands which may probably be ascribed to certain electronic transitions in the bivalent Mn ion. On irradiation with light from one of the three absorption regions, luminescence of the known Mn bands is always obtained, and on exposure to light from the two firstnamed absorption regions both phosphorescence and fluorescence are obtained, while irradiation with the bands in the third region characteristic of Mn results in fluorescence only. In conclusion, measurements were made of the connection between the intensity of luminescence and the temperature as well as the Mn content of the phosphor.

1413: W. Elenbaas: Über eine Kombination der hydrodynamischen Theorie des Wärmeübergangs und der Langmuirschen Theorie II (Physica, **6**, 380-381, April, 1939).

Continuation of the investigation outlined in Abstract No. **1255**, which discusses a functional relationship between two magnitudes purely on graphical lines.

1914: Balth. van der Pol and H. Bremmer: Further note on the propagation of radio waves over a finitely conducting spherical earth (Phil. Mag., **27**, 261-275, March, 1939).

It was shown in the paper referred to in Abstract No. **1338** that the Bessel functions which occur in the analysis of the distribution of field strength over the earth can be approximated in two different ways, *viz.*, either by the more simple tangent approximation or by the more accurate Hankel approximation. The calculations outlined in Abstract No. **1264** are repeated in this paper by applying the Hankel approximation, the results being closely comparable to the geometric-optical approximation applying for points in front of the horizon, so that the variation of field strength can be determined from the immediate neighbourhood of the emitter up to points in the "shadow region".

1415: W. Elenbaas: Energieafgifte aan het gas en verdampingssnelheid van een gloeidraad als functie van de druk (Ned. T. Natuurk., **6**, 77-88, 1939).

For details of the contents of this paper see Abstracts Nos. **1255** and **1413**.

1416: M. J. O. Strutt and A. van der Ziel: Some dynamic measurements of electronic motion in multigrid valves. (Proc. Inst. Rad. Eng., **27**, 218-225, March, 1939).

The authors describe modern methods for measuring the admittance on short waves, dealing with the admittance between the input grid and cathode as well as the complex transconductance A pentode with negative first grid, positive second grid, negative or positive third grid and positive anode is discussed in detail. A calculation is given of how the admittance at the input grid is affected by the electrons which turn back in front of the third grid. Comparison of these calculations with measurements on pentodes, hexodes, heptodes and octodes enables the number of returning electrons to be calculated in various ways, so that an overall check is provided. Formulae are also given for the effect of the returning electrons on the complex transconductance and these are applied to the measurements made.

1417: F. A. Kröger: Formation of solid solutions in the sytem zinc-sulphide/manganese-sulphide (Z. Kristallogr., (A), **100**, 543-545, March, 1939).

By heating a mixture of zinc sulphide and manganese sulphide using potassium chloride as a flux, mixed crystals of zinc/manganese sulphide are obtained. At 1180 deg. C. mixed crystals are obtained containing 0 to 52 molecular per cent of manganese sulphide. With higher percentages of manganese sulphide pure green manganese sulphide separates out as a second phase. According to the temperature to which the mixture is heated, the mixed crystals with low manganese sulphide are either of the Wurtzite or Sphalerite type. With a higher content of Mn a Wurtzite structure is always obtained.

1417A: J. W. M. Roodenburg: Tien jaar plantenbestraling (1928-1938). (Vakbl. Biol., **20**, 137-148, April, 1939).

A survey is given of the results obtained in the irradiation of plants in glasshouses using electric light. These investigations have shown that the light needs of plants can be resolved into at least three different processes: Assimilation of carbon dioxide, effect of the length of daylight, and the action of blue light. These processes can be promoted by irradiation with neon, incandescent mercury-vapour lamps.

1418: J. A. M. van Liempt and J. A. de Vriend: Studien uber das Verbrennungslicht einiger Metalle und Legierungen II. (Rec. Trav. chim. Pays Bas, **58**, 423-432, April, 1939).

Determinations are made of the quantity of light, light yield and duration of flash produced by the combustion of pure thorium and titanium, as well as of aluminium alloys containing zirconium, titanium, calcium, lithium or zirconium/magnesium. The term, a "photographic" lumen-second, is proposed as a unit for measuring the quantity of light furnished by flashlights.

1419: J. A. M. van Liempt and J. A. de Vriend: Die Lichtausbeute von Steichhölzern (Rec. Trav. chim. Pays Bas, **58**, 433-434, April, 1939).

The quantity of light emitted by the head of an ordinary safety match is approximately 150 lumen-secs., and the yield of light 3 lumen-secs. per watt. The duration of the flash with a bundle of 60 matches is 1 sec.